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Automatic Detection of Visual Change

An analysis of visual mismatch and its relationship to
impulsivity

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By

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Chapter 1

A general introduction to change detection

1.1 Voluntary attention

The sensory system of the brain is deluged with information from the different modalities like hearing, vision or somatosensis. Only parts of the vast amount of information which so reaches the brain can be completely processed and be brought to conscious awareness. However, not all of the information received has high relevancy or needs to be brought to complete awareness. Of biggest importance is the information which enables goal-directed behaviour and information which is needed to avoid potential hazards.

The brain has a control mechanism in place to select which information will or will not reach the highest level of information processing and conscious awareness. Part of this control mechanism functions as a top-down regulator, which means that it is possible to consciously change the focus of this regulator to a particular source of stimulation in the information flow, thus allowing for the gathering of more precise information from this particular source (selective attention). This regulator is called attention (Matlin, 1983). Attention is a difficult concept to define and is best described by situations and phenomena in which it is commonly used.

One such situation is the concurrent streams of voice input at a cocktail party where all people are speaking at the same time. The listener is able to focus his attention actively to a single speaker among a mixture of conversations and background noises, while simultaneously ignoring these conversations and other sounds (Arons, 1992). Alternatively, attention can be grabbed suddenly by a certain stimulus. If someone at the other side of the room suddenly calls out the listener's name, it causes an immediate response e.g., by turning the head towards the source of the sound. This shows that it is hard to define under which circumstances attention is really under conscious control.

1.2 Passive attention

In 1890 William James introduced the concept of passive attention. In the previous example voluntary or active attention was involved in following a chosen conversation. However, loud abrupt sounds, significant stimuli like the calling of one's

name, infrequent events, and unfamiliar objects tend to attract or shift the attention away from the task concurrently performed.

Experiments have demonstrated that a stimulus has to have certain features to be able to elicit an attention switch: intensity and suddenness. It is also well-known that occasional changes in to-be-ignored input of repetitive nature easily cause an involuntary attention switch (Escera, Alho, Schroger, & Winkler, 2000; Escera, Corral, & Yago, 2002; Berti & Schröger, 2006; Berti et al., 2006). A familiar example is that of a clock which suddenly stops ticking because the battery has run out. Although the ticking had gone unnoticed before, the attention is suddenly switched towards the peculiar silence the ticking has left behind. It is important to realise that for these stimuli to be able to call for attention they must have been processed up to a certain level in the information processing system.

Stimuli that elicit passive attention can in turn elicit an orienting reflex (Sokolov, 1963). This involves a complex pattern of overt and covert bodily changes like postural changes to maximise the reception of the sensory organs, the immediate termination of ongoing motor behaviour. Also autonomous changes can be observed like the dilation of the pupils and changes in the skin conductance response (Alexander et al., 2005; Stelmack & Siddle, 1982). When attention is caught by such a salient stimulus, away from the task performed, usually it is instantaneously pulled back to the task (voluntary attention). Ususally, the duration of passive attention towards the stimulus which caused the switch of attention depends on the time that is needed for recognition and evaluation of the stimulus (Näätänen, 1992).

The phenomenon of attention switch had already been described by Pavlov who called it the “investigating reaction” or the “what is it” reaction. He associated the cerebral events leading to the elicitation of this response with the very early processing of a novel stimulus or a stimulus change. More recently, Öhman et al., (Ohman & Soares, 1993) postulated the term ‘gateway to consciousness’. According to their theory the orienting response results from early cerebral events which occur before the stimulus has been fully processed.

Data underlying the existence of the orienting response come from the classical paradigm called the repetition-change paradigm (Verbaten, Woestenburg, & Sjouw, 1979; Zimmer, 2001). In such an experiment a sequence of homogeneous stimuli is

presented. These stimuli are presented with a relatively long inter-stimulus-interval to allow for the recording of slow autonomic responses. Obviously, the first stimulus in a sequence elicits an orienting response, but after a certain amount of repetition (5 to 20 trials) this response is completely extinguished due to habituation¹. If then some feature of the stimulus is changed, the orienting response is elicited again. Sokolov's explanation for this phenomenon was that a neuronal representation of the physical characteristics of the stimulus is developed, which inhibits identical input to elicit such an automatic response. When a change in the characteristics of the repeated stimulus is introduced the afferent input is no longer inhibited by the neuronal representation and an orienting response will be released. Later, the important distinction was made between the reaction to the first stimulus in the sequence and the reaction to the change. Because no inhibiting neuronal representation can be present when the first stimulus of the sequence enters the system.

1.3 Attention and automaticity in information processing

As was described above, attention plays a crucial role in the processing of information. Much of the information processing occurs in the brain without the need of any voluntary effort or attention. It can be said that it happens automatically. Posner and Snyder proposed three criteria for a process to be purely automatic (as cited in Näätänen, 1992). The process occurs (1) involuntary or without intention, (2) without giving rise to any conscious awareness, and (3) without producing interference with other ongoing mental activity.

For example, looking at a word (e.g., tree) it is difficult not to quickly read the word "tree". Most people are so proficient at reading words that they cannot easily ignore reading them without using considerable mental effort or in other words: the word is read unintentionally. One leading example for this type of automatic processing is the performance on the Stroop task, which is based on reading a word quickly and automatically. In this task, the name of a colour is presented while it is printed in a different colour. The subject is then asked to name the colour of the ink. Because words are more readily processed there is an automatic involuntary vocal response to the printed word which is competing with the actual task of naming the colour of

¹ Habituation refers to the tendency to stop attending to, or noticing of stimuli as they become familiar.

the ink. Consistently, when ink colour and the word share a common colour name it facilitates recognition and performance on the task is increased. This is a further example showing that it is not always possible to avoid processing of certain aspects of the input, which one may wish to ignore.

The second criterion for an automatic process is that it should occur without giving any rise to conscious awareness. In an alternative version of the Stroop task (Swinney, 1979) it was shown that the subject might be quite unaware of the activation patterns produced by the input words. In this case, subjects listened to lexically unambiguous sentences that ended with an ambiguous word (e.g., bank). In some trials the meaning of the word was disambiguated by the context, in others it was not. Each sentence was then followed by the visual presentation of a word printed in coloured ink. The performance on the task was measured by the time it took to name the colour of the ink. This response time was longer when the printed word was related to the last word of the sentence than when the printed word was not. The striking finding in this study was that the response time was also longer for printed words which were corresponding to the other meaning of the ambiguous word not indicated by the sentence context. The results from the Stroop test showed that both meanings are activated independently of the subject's conscious perception.

The third criterion for pure automatic processing is that it should not cause interference with other ongoing mental processing. A good example can be found in dichotic stimulation studies (e.g., (Hugdahl et al., 2000)). Dichotic listening is commonly used to investigate selective attention in the auditory domain. Using a set of headphones a different message is transmitted into each ear, simultaneously. The subject is told to carefully attend to one ear only and is requested to shadow the message delivered to that ear. Shadowing involves listening and then repeating the message heard out loud, which the subjects found relatively easy to accomplish. However, the interest of the researchers went out to what subjects remembered from the message transmitted to the unattended ear. It was found that subjects were able to distinguish certain physical or acoustic properties of the unattended message. Subjects could report whether the unattended message had been noise or a human voice and could even determine whether it was a male or female speaking although little knowledge on the meaning of the messages of the unattended ear existed. Still,

the information obtained through the unattended ear did not interfere with the primary task of shadowing.

Summarising the previous paragraphs it can be said that the concept of automatic processing refers to a type of processing which the system seems to be able to do without intention, awareness and capacity limitations. It is also regarded as opposing controlled processing of information. Both in vision and audition studies have been performed which were able to support the concept of automatic processing. It was shown that physical stimulus features providing sensory information for a percept appear to be automatically processed to a high cognitive level.

1.4 Theories of attention

The findings from previous studies have demonstrated that information can be processed with a certain automaticity. This processing was described by Schneider et al. (as cited in Näätänen, 1992) as fast, parallel and fairly effortless and not limited by a short-term memory capacity, nor is it under direct control of the subject. The action of automatic processing is not conscious but the stimulus information extracted by these processes may become consciously represented at some stage. Already in the mid-seventies Neisser (see also Näätänen, 1992) described these processes as the preconscious or preattentive analysis of stimuli. These preconscious processes are activated by the occurrence of an appropriate stimulus irrespective of the state of the organism. It also occurs during sleep, which underlines its unconscious nature and its independence of voluntary attention.

Treisman and Gelade (as cited in Best, 1992) used this principle as a base for their feature-integration theory of visual processing. They suggested that different basic features of visual stimuli such as colour, form or orientation are analysed in parallel by feature-detector systems and that the role of attention would be to combine the outcomes of these systems to a coherent perception of the object. In addition, Julesz and Bergen (as cited in Best, 1992) developed the texton theory of preattentive vision, which also proposes a preattentive visual analysis system resembling the feature-integration theory. Textons refer to fundamental micro-structures in natural images which are the basic elements processed in early (Franken, Nijs, & Van Strien, 2005) visual perception. In contrast to the feature-integration theory, the texton

theory not only allows for automatic processing of features but also of feature conjunctions. The system proposed by Julesz and Bergen allows for the detection of differences in local features (or process information in parallel), regardless of where they occur in a large visual field. Julesz and Bergen regarded the preattentive system as an early warning system, which calls the attention to loci of texture differences for closer scrutinising by the attentive part of the visual system. The data underlying these two theories of preattentive vision indicated to the authors that a great number of parallel processes which were regarded as fully automatic occurred during visual analysis. They occurred irrespective of, and were most likely unaffected by, the direction of attention.

In the previous paragraphs some theories and rules confining the concept of automatic processing were described using examples from the fields of hearing and vision. In the following paragraphs several very influential information processing theories will be described leading us to the issue of what happens with information which is automatically processed, but not relevant to the task.

Sternberg developed a model for information processing (Sternberg, 1969) named the Additive Factor Method (AFM). According to this, information processing consists of successive stages where one stage only starts after the result of the previous processing stage has been completely transferred. The information passes through the different stages until a meaningful representation of the information is obtained and a reaction is chosen. The reaction time was taken as the measurable end product of the information processing. Therefore, he hypothesised that if two factors are affecting different stages they must have additive effects on reaction-time measurements.

Pribram and McGuinness (1975) viewed the information processing from a different perspective. They designed a model consisting of three different resource systems: two basal systems, the Arousal and the Activation System, and one system controlling these two systems. They postulated that these systems are responsible for the finer control of the arousal or attention. The Arousal System refers to the phasic rise in arousal in the sensory areas, the Activation System refers to the tonic arousal in the motor areas and represents the readiness to respond. The superordinate system is Effort, which has control over the two basal systems and is therefore the key in providing controlled information processing.

Sanders (1983) in turn integrated the theories from Sternberg and Pribram and McGuinness and so used them as a foundation for his complex cognitive-energetic model consisting of three levels. The basic idea behind the model is that mental processes are represented in the reaction time: the performance on a task depends on the ability of the participant as well as the status of the organism (e.g., motivation). Sanders postulated that there is a relationship between motivational (energetic) systems and the different steps in information processing. In combining these, the model allows to investigate and localise the effects of the status of the organism on the information processing.

At the base level Sanders differentiates between four clear-cut cognitive stages of information processing (i.e., preprocessing, feature extraction, response choice, and motor adjustment). The first level is connected to the energetic systems on the second level i.e., the Arousal system, the Activation system, and Effort derived from the model developed by Pribram and McGuinness. At the third level of Sanders' model the evaluation mechanism is controlling the division of resources (see Fig. 1.1).

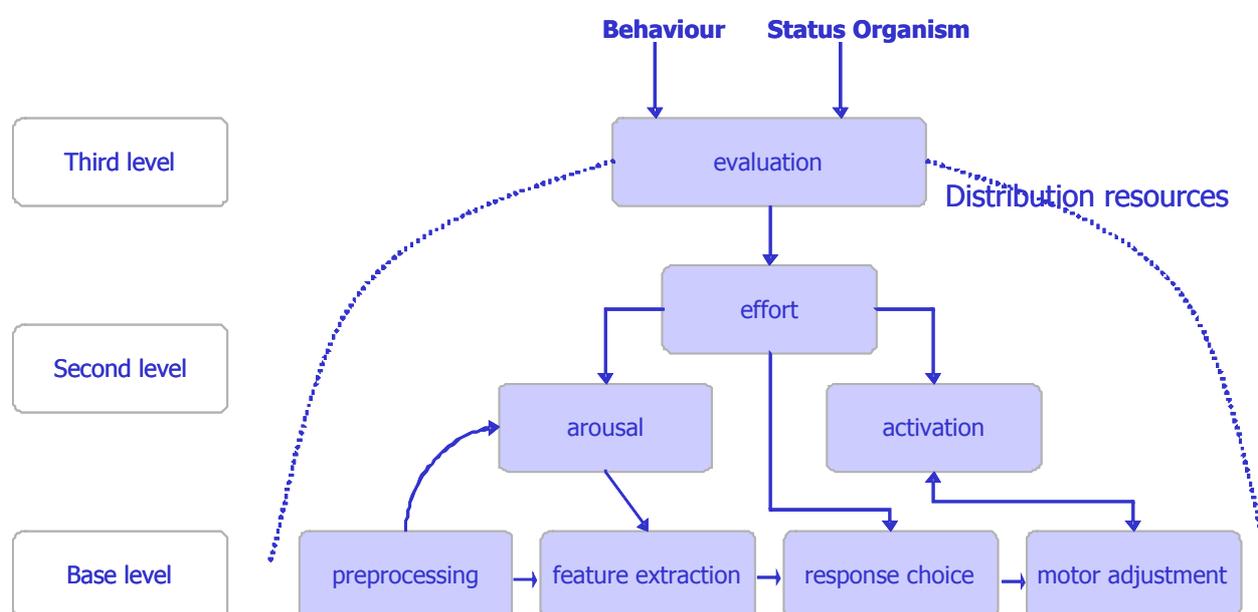


Figure 1.1. Graphical representation of Sander's cognitive-energetic model.

At the first level, the four stages are all associated with experimental task variables and manipulating these variables will lead to a change in outcome i.e. reaction time. Preprocessing, which is the first stage, is representative for the automatic part of stimulus analysis and does not require any resources. From this stage there is a

direct connection to the energetic arousal system on the second level. Thus, incoming stimuli in general cause an enhancement of the energy intensity of the arousal system, which in turn can be transferred to and is used in the second stage, the feature extraction stage. The concept of this arousal response to stimuli is closely associated to the orienting response described by Sokolov, which will be described in a later part of this chapter.

The second stage of feature extraction is representative for perceptual processing and is considered a resource intensive process. During this stage of processing relevant stimulus information is actively differentiated from irrelevant information. This concept follows the theory of selective attention by Posner (as cited in Best, 1992). It postulates that the more salient a stimulus, the more resources, allocated from the arousal system, will be available for the feature extraction process.

The third stage or the response choice stage represents the central, controlled and resource intensive processing of information. The energy for this stage comes from the effort system on the second level.

At the second level of the model three energetic systems are defined. Each of the energetic systems is thought to have its specific role in the process. The arousal system represents the rise in arousal in the sensory areas caused by the preprocessing which therefore is time-locked with stimulation. A second system is the activation system which represents the tonic arousal in the motor areas and thus the readiness to respond. The third energetic system is effort and is superordinate to both the arousal system and the activation system. It has been postulated that this system has more than one function. One of its functions is to regulate the energy when the current state of the organism does not meet the state required to perform a certain task. Effort is also capable of separating the connection between the two other energetic systems when it is required so as to safeguard optimal information processing.

On the third and highest level of the model is an evaluation mechanism responsible for the distribution of resources. This mechanism also receives feedback about the behaviour and the condition of the organism and it can change certain behaviour through systematically controlling the actions of effort.

In Sander's model automatic processing takes place at the first level in the preprocessing stage. Information automatically enters the system and through the orienting response the attention is automatically drawn to this input. Theories on attention, which also encompass the orienting response, bring a better understanding of what could be taking place. In the next paragraphs some theories postulated on attention are discussed, starting with older ones which form the basis for more recent ones.

The filter theory of Broadbent proposes that the focus of attention is determined by three components: a selective filter which leads to a channel of limited capacity and in its turn leading to a detection device. While recent stimuli are stored in some type of register they are subjected to a preattentive analysis, which determines some of their physical characteristics. Based on this analysis the selective filter determines which information will be processed further. Information that is not selected is tuned out and no further processing of it takes place. According to Broadbent, we only know or become aware of about stimuli that make it past the selective filter, because the filter is unable to determine a stimulus' meaning. Although a very influential theory, it was not thought to be completely correct. Shadowing studies showed that information presented to the non-shadowed channel could become meaningful (e.g., dichotic listening). This is not compatible with the theory of Broadbent because non-shadowed input should be tuned out in the preattentive analysis and would never receive further processing and therefore cannot become meaningful in any way.

Based on empirical data Treisman proposed a modification of Broadbent's theory, which is known as the attenuation model. This model maintains that the preattentive analysis is much more complex. In contrast to the filter theory the processing of non-selected input is not based on an all-or-none principle, but the input is attenuated or dampened instead of tuned out. Although Treisman's theory provides a good account for many of the phenomena associated with selective attention, it was found to have serious shortcomings. One critical note was that the theory suggested a too complicated preattentive analysis. The theory postulates that preattentive analysis is almost as complete as the attentive analysis. And if these two ways of processing are so similar, why have both?

Next, late selection theories (Best, 1992) were postulated, which proposed that almost all of the input is sent on for further processing and selection takes place only

once the input reaches the working memory. In working memory a judgement is made about the importance of the input and only that is processed further. The patterns formed and recognised in working memory are what becomes the basis of our awareness.

Although this overview of the bottleneck theories of attention is far from complete, it does give a good account of what could theoretically take place during information processing. In general it is thought that part of the information processing seems to be automatic until at some point the importance of the input is judged and that input receives more processing which in turn leads to it becoming information of which we are conscious or aware.

Automaticity in information processing has been an important aspect of the research on (selective) attention. Theories on information processing not only involve the controlled processing of information or the stimulus selection process, but they also incorporate the automatic processing of information. Voluntary and involuntary factors compete for the control over the direction of attention. Involuntary switches of attention are caused by e.g. onset or offset of a stimulus, change, or irregularity in the information stream. The mechanism involved in the involuntary switches of attention (Verbaten et al., 1979) seems to have significant importance for us by pointing our attention seemingly automatically towards environmental sources of information which could potentially be hazardous if they remain unnoticed.

1.5 Neural correlates of automatic information processing

Neural correlates associated with the automatic processing of information came from electrophysiological research involving target detection tasks and oddball tasks in the visual and auditory domain (Brazdil, Rektor, Daniel, Dufek, & Jurak, 2001; Czigler, Balazs, & Pato, 2004; Litzelman, Thompson, Michalewski, Patterson, & Bowman, 1980; Pins & Ffytche, 2003). The neural correlates involved are known as the N1-P2 complex.

The N1 component denotes a negativity usually peaking about 100 ms after the onset of stimulation. This component does not represent one single cerebral event, but its response and topography can vary with the experimental manipulation (Näätänen & Picton, 1987). It is associated with perceptual detection of a discrete

event in the auditory or visual environment. The P2 component of this complex denotes a positivity around 200 ms after stimulation and is thought to be related to stimulus evaluation (Potts, 2004). In general, research seemed to indicate that the N1-P2 response is initiated by a change from sensory rest, like a steady stimulus or silence, to sensory change. For example, in response to a first stimulus in a series both the N1 and P2 are much larger than those to subsequent stimuli (Grau, Fuentemilla, & Marco-Pallares, 2007). The response was attenuated by repetition of the same stimulus. Introducing a different stimulus caused the N1-P2 complex to show a normal response again (Mangun & Hillyard, 1988; Nielsen-Bohlman & Knight, 1999). An interesting variation on this principle involved a series of repeated auditory stimuli which were interjected by somatosensory stimuli. The N1-P2 response attenuated on presentation of a series of repetitive tones, but when a somatosensory stimulus was inserted in the series the N1-P2 response did not recover and remained attenuated as if no change had been induced. It was concluded that the change had to occur on the same input channel in order for the N1 response to recover.

1.6 *Habituation or refractoriness*

As discussed in Chapter 1.5 repetition of sound or visual stimuli typically causes attenuation of the N1 amplitude. Whether the attenuation is due to the refractoriness of the N1 generators or to habituation has been debated at large (Budd, Barry, Gordon, Rennie, & Michie, 1998; Gutschalk, Patterson, Uppenkamp, Scherg, & Rupp, 2004; Näätänen, 1992; Sable, Low, Maclin, Fabiani, & Gratton, 2004).

To understand this debate it is imperative to know the meaning of refractoriness and habituation. The assumption central to refractoriness is that the neural network generating the N1 shows a phenomenon similar to the one found on a single cell level and closely spaced stimulation does not allow adequate recovery of this network (Kenemans, Jong, & Verbaten, 2003). Habituation has been defined according to three criteria: (1) the gradual reduction in responsiveness to a repeated stimulus, (2) response recovery after a change stimulus is presented in a series of repeated stimuli and (3) dishabituation or the increase in response to a previously habituated stimulus following the change or novel stimulus in a series of repeated stimuli (Sokolov, 1963, as cited in Thompson and Spencer, 1966). One way to distinguish between the two is that amplitude attenuations due to refractoriness

should stabilise immediately after repetition of a stimulus, where habituation should show a more progressive decline in amplitude.

Budd et al. (1998) very clearly summarised the results of several studies in their article supporting the refractoriness. It was shown that stimulus repetition per se provided no significant effect on the N1 attenuation. Even when increasing the inter-stimulus interval beyond the time interval where an initial response attenuation was observed, no further decrease in amplitude was found. If this would have been due to habituation, then the attenuation would have been progressive. In an experiment involving a series of repetitive tones this became evident. There was a normal N1 response to the first tone in the series, but attenuation in the response to the second tone. The response to tone five was similar to the response to tone two. No gradual attenuation indicating a habituation response was found. This result is consistent with the view that the attenuation reflects a refractory period of the neuronal network involving the generation of N1.

In summary it can be said that the N1 and P2 respond to characteristics of stimuli and show attenuation due to refractoriness when a series of repetitive stimuli is presented. When a change in one of the characteristics is presented then this response is recovered.

1.7 Mismatch negativity

Studies of the recovery of the N1-P2 complex formed the basis for investigations into the ability of the brain to rapidly become aware of discrete, unexpected changes in the environment which is further referred to as change or deviance detection. Besides the N1-P2 complex another ERP component, known as the mismatch negativity (MMN) can be extracted from the ERP measurements. This component was discovered in studies investigating the change detection in the auditory modality.

The classical paradigm (Sams, Paavilainen, Alho, & Naatanen, 1985) utilised to investigate this mismatch phenomenon is composed of blocks of auditory stimuli consisting of standard stimuli of 1000Hz in 80 percent of the trials and deviant stimuli of a slightly higher frequency in 20 percent of the cases. In different blocks this deviant stimulus has different frequencies of either, 1004, 1008, 1016 or 1032 Hz. Within a block, the order of the stimuli is randomised and the inter-stimulus interval is

kept constant. The tones are administered over a set of headphones and during presentation the subjects are instructed to attentively read a book. Meanwhile, the encephalographic signals are recorded. The ERP results showed that the N1 evoked by the deviant stimuli is quite similar to the N1 elicited by the standard. This is because the two types of stimuli are very similar. The difference in response evoked by the standard and the deviant became clear once the waveform to the deviant was subtracted from the waveform to the standard: The difference wave. Comparison with the tone of 1004 and 1008 Hz did not show any measurable difference between the waveforms. However, for frequencies of 1008 Hz and higher a negativity in the difference waveform was seen commencing around a 100 ms after stimulus onset and lasting until about 250 ms after stimulus onset. This study also showed that with an increasing deviation the negative shift of the waveform became larger.

Another experiment, involving the active participation of the subject in detecting the deviants, showed that even undetected deviating stimuli elicited a MMN. Moreover, the magnitude of the MMN was about the same as the magnitude for correct detections of deviant stimuli. The interpretation of this research was that “the MMN is generated by an automatic cerebral process that is a necessary, but not sufficient condition, for the conscious perception of a stimulus change” (Näätänen, Gaillard, & Mäntysalo, 1978; Näätänen, 1992).

The discovery that the brain responds to change stimulated research into which circumstances trigger this effect and which factors could affect this negative shift. Because it is beyond the scope of this work to report the studies in detail only the results will be discussed. It was found that the MMN does not just occur after a change, but only after a change in a sequence of repetitive stimuli (Näätänen, Paavilainen, Alho, Reinikainen, & Sams, 1989; Sallinen, Kaartinen, & Lyytinen, 1994). The MMN was not elicited by the first stimulus in a sequence or when the inter-stimulus interval was too long. Therefore, it was concluded that a stimulus per se is not adequate for a MMN to be elicited; it has to be a stimulus in a certain setting. Only the relationship between the deviant stimulus and the standard stimuli will evoke a negative shift of the waveform.

The question on which mechanism could underlie the rapid change detection caused great debate. Two hypotheses on change detection have been proposed: rareness or memory trace comparison. The rareness hypothesis postulates that change detection

could be due to a rating of the rareness of the inputs: A high frequency of appearance is related to refractoriness and a rare occurrence is not. The alternative theory is the memory trace hypothesis, where the response is based on comparing new inputs to templates of events in the immediate past. This comparison results in a mismatch reaction after presentation of a change in the stimulus features of a series of standard stimuli.

These two hypotheses have been explored for visual change detection making use of a simple paradigm (Astikainen, Ruusuvirta, Wikgren, & Korhonen, 2004; Kenemans et al., 2003). In one condition the usual oddball paradigm with 90% standards and 10% deviants was presented. In the second condition the same sequence was presented except that the standards were omitted (deviant-only). The ERPs to the deviant and the deviant-only were compared. Kenemans concluded that the occipital response to the deviant depended on rareness. However, the findings from Astikainen and colleagues supported the memory trace hypothesis. They found no negative displacement in the deviant-only condition suggesting that this displacement could only be found in response to stimulus change in a repetitive series and not in the case of rareness. Since different visual stimuli were used in both studies it was argued that the memory trace hypothesis might not be applicable to all visual attributes.

1.8 Top-down modulation



Figure 1.2. Depending on the way the picture is looked at an young or an old woman can be seen

Usually perception is an organised process. The sensory system translates physical characteristics of a stimulus, like shape and colour in vision and sound frequency and intensity in hearing, into meaningful objects. We see a table or hear a telephone. This is mainly a stimulus-driven or automatic perception. We perceive the objects or sounds as a whole and do not, for example, see the parts it is assembled from, like legs and tabletop. There are, however, situations in which the sensory input is ambiguous and the stimulus can be perceived in more than one way. When presented with an ambiguous stimulus like the young old woman (see Fig. 1.2) the

physical stimulation is identical, but depending on our intent or top-down control, we exclusively see either the young woman or the old woman. When it is known that the figure can be perceived in two ways, the perception can be changed by actively changing the focus of attention on different aspects of the stimulation.

One of the questions asked in the literature was whether the detection of change (or the generating of the mismatch negativity) is sensitive to top-down control. An example of an investigation showing that the regularity template or sensoric representation underlying the MMN are not affected by top-down processes was done by Rinne, Antila & Winkler (2001). They designed a study where the MMN was measured in two situations. Subjects were asked to perform a series of button presses using two buttons, one was to be pressed frequently and one infrequently. In the unpredictable situation, each button press produced a tone from a prearranged series of standard and deviant tones. In the predictable situation, the frequently pressed button produced a standard tone and the infrequently pressed button a deviant one. On comparison no difference in MMN amplitude, latency and scalp distribution was found, suggesting that there is no top-down control over the mechanism that produces the MMN.

However, in a series of studies by Sussman and colleagues (Sussman, Gomes, Nousak, Ritter, & Vaughan, 1998; Sussman, Ritter, & Vaughan, 1998; Sussman, Winkler, Huotilainen, Ritter, & Näätänen, 2002) where different sets of instructions were given on the same stimulus material showed that the different instructions and information given to the participants did affect the way the sound sequence was perceived. The different instructions were (1) to read a book and ignore the sound, (2) to focus on pitch changes in the sound sequence and respond to the tone with the lowest pitch (3) to focus on violations of the pattern in the sound sequence. A randomised and a patterned sound sequence were used, consisting of three tones: a frequently presented tone (Sussman et al., 1998), and two infrequently presented tones (T2 and T3). The patterned sequence existed of series of five tones; four standards tones (Sussman et al., 1998) followed by a deviant fifth tone (T2). Occasionally, the third tone (T3) was intermitted. The results on the randomised sequence showed that independent of the instruction the T2 and T3 elicited an MMN. However, the patterned sequence only elicited an MMN in the ignore condition and attend-to-pitch condition, but not in the condition where one was to attend to

violations of the sequence. These results suggested that in most circumstances (the ignore condition and the attend-to-pitch condition with randomised and patterned sequences) the sound sequence was represented in terms of a single repeating tone in the memory underlying the MMN-generating process. When the subjects were instructed to perform a task based on the repetitive pattern, T2 was processed as part of the standard and therefore did not elicit an MMN, whereas T3 did elicit an MMN. This demonstrates a top-down modulation of the stimulus-driven sound organisation, altering the information that is used in the MMN process. That is to say, the neural representation that underlies the MMN-generation seems to be reorganised. These studies indicated that although the stimulus-driven sensory mechanisms form the basis of sound organisation, attentive processes may in certain cases modify the neural representation of sound in accordance with current goals of behaviour.

1.9 *Detection of change in the visual modality*

One can imagine that such a system which is able to detect sudden changes in the environmental information stream could have had a considerable contribution to the survival of the species. An example for a sudden change in the auditory information stream is as follows. When a man was after prey in the woods and there was suddenly a crackling in the coppice, it would benefit his survival if this sound was selected from the large stream of auditory information for further processing, so that he could discover the lion on time and make an escape.

Continuing along these lines, it would not be unimaginable to think that such an automatic detection system for unexpected changes in the environment is not only available for the processing of auditory information, but would be available for the processing of other sensory information as well. Typical natural scenes are composed of a multitude of visual objects. The visual system is able to select one or more of these objects for a more thorough analysis by willingly putting it in the focus of attention. The detection of sudden changes in this natural scene could be an additional biologically relevant feature of the visual system: it allows for the selection of meaningful events (e.g., a warning signal) for further processing. In the late eighties and nineties several investigations could not satisfactorily demonstrate the existence of a visual or somesthetic phenomenon analogous to the auditory MMN

(Nyman et al., 1990; Neville & Lawson, 1987). To be able to demonstrate the existence of a visual counterpart to the auditory MMN it is important to review the aspects around the emergence of the auditory MMN. The functional significance is to initiate an attention switch (Verbaten et al., 1979) to the eliciting stimulus change (Näätänen, 1992; Näätänen, 1990; Näätänen & Michie, 1979). It is known from the orienting response that it can be triggered not only in the auditory modality but also in other modalities. This was seen as an indication that the MMN could also occur in other modalities. In addition, Verbaten (1990) noted that the auditory and visual modalities are based on different processing principles, but in both modalities occasional deviating stimuli are perceived. According to Verbaten this should be enough reason to search for a change detection system in the visual modality.

The theoretical explanation for mismatch detection is that it is elicited when a discrepancy between the neural representation of the regularity in the recent information stream and the representation of the current stimulus is automatically detected by the memory-comparison system. The existence of such a memory-comparison system in vision was long time debated. One point of discussion was the occurrence of change blindness, which is a phenomenon in visual perception where apparently large changes in a scene are not detected by viewers. This typically occurs when the change coincides with some disruption such as an eye movement or a brief obscuring of the observed scene (Henderson & Hollingworth, 1999; Rensink, O'Regan, & Clark, 1997). The phenomenon of change blindness was a large argument against the existence of a memory system in vision.

However, further investigation provided evidence that representations from previously attended objects can be retained robustly in visual memory (Hollingworth, Williams, & Henderson, 2001; Hollingworth & Henderson, 2002). These findings were interpreted as change blindness deriving from retrieval and comparison failures, but not from a lack of visual memory. It was concluded from studies like these that the failure to detect an unattended change does not mean our visual system cannot register the change. Some studies have demonstrated that even though a change cannot explicitly be detected, effects of that change could be observed with other measures that are perhaps more sensitive like utilising forced guess (Fernandez-Duque & Thornton, 2000). Additional data supporting that considerable cognitive visual processing is possible without conscious awareness came from studies on

patients. In a study with brain-lesioned patients suffering from blindsight, patients reported not being able to see an object but were nevertheless able to guess the location of an object with reasonable accuracy (Weiskrantz, 1997). These studies indicate that visual processing can take place without awareness, however, it seems impossible to explicitly detect a change without attention. The question arising from this statement is that if for the detection of a change attention is required, how can we ever become aware of unexpected information? There is a mechanism suggesting that automatic differentiation of information does take place. One example can be found in visual search, which involves an active scan of the visual environment for particular objects or features. Common examples include trying to locate a certain brand of cereal at the grocery store or a friend in a crowd.

For scientific purposes this concept was simplified into a more abstract search. For this task a display can be used with targets and distractors (see Fig. 1.3). In this case distractors are non-target stimuli (**X**) that divert attention away from the target stimulus (**O**). In Fig. 1.3 the **O** pops-out from the **Xs** and the target seems to automatically capture the attention (Berti & Schröger, 2001; Julesz, 1984; Theeuwes, 1992). Johnston and colleagues

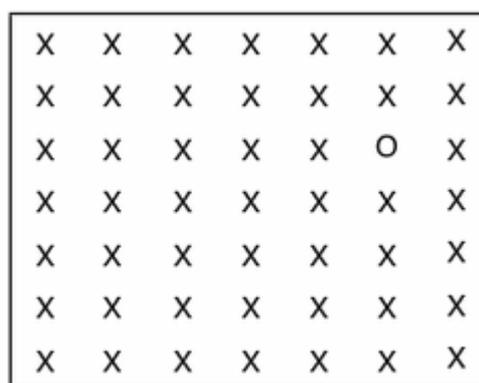


Figure 1.3. Pop-out effects in a visual search task O has a very distinct feature and “pops-out” compared to the distractor X (Adapted from Berti & Schröger, 2001).

(Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990) proposed that the pop-out phenomenon in vision and the detection of deviance in a stream of auditory information may indicate that these two phenomena could have similar underlying mechanisms. Berti and Schröger (2001) are convinced that the pop-out phenomenon may also indicate the distraction process that takes place in vision and is produced by a preattentive deviant detection mechanism, which is an obligatory stage in the processing of the stimulus which may or may not be followed by a reorientation of attention to stimulus changes.

1.10 Short outline of the thesis

A short summation of the information included in this chapter can be made at this point. The existence of different types of attention, like passive or active attention, the occurrence of the orienting reflex in vision, the behavioural outcome in experiments on visual automatic processing like the Stroop test, or visual search experiments showing the pop-out effect, as well as, the evidence presented on the existence of visual memory were discussed. All of the theories and observations described seem to warrant an investigation into the visual change detection system. Especially, when it is considered that a properly functioning mechanism for the detection of sudden and unexpected changes could have been of great importance for the survival of the species. Because if not for this warning system how else would we become aware of changes in our visual surroundings?

In the next chapter the methods used to explore this visual mechanism will be described. In Chapter 3 and Chapter 4 the application of the methods in two experiments on visual change detection will be reported. And last but not least in Chapter 5 it will be explored whether impulsive behaviour could be associated to how well the change detection mechanism performs.

Chapter 2

Methodology

2.1 The basic principles of electroencephalography

What is known from behavioural research is that a given stimulus triggers physiological responses in the human body which lead to a reaction or response to that stimulus. The processes occurring in between stimulus and response are not easy to capture and a long time this gap has been named the black box: it is known what goes in and it can be measured what comes out, but what happens in between remains unclear. To elucidate what goes on in the black box physiological processes can be monitored. Electroencephalographical measurements are non-invasive measurements which are performed by recording the electrical activity in the brain by placing multiple electrodes on the scalp. This technique is called electroencephalography (EEG) and can be used in addition to behavioural research to find support for theories on information processing in the human brain. The scalp electrodes measure the voltage differences between different parts of the brain. These measurements represent the electrical signal from a large number of individual nerve cells or neurons.

The basic unit of nervous function is the nerve impulse, which is the firing of an individual neuron, the simplest element in the system (Gleitman, 1991). This cell can be subdivided in three parts: the dendrites, the cell body and the axon (see Fig. 2.1).

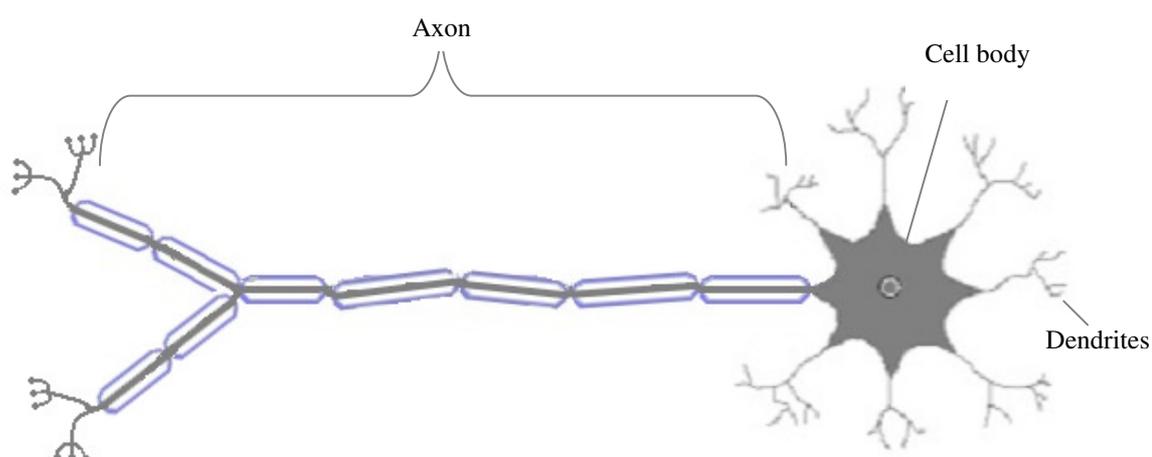


Figure 2.1. A schematic diagram of the main parts of a typical neuron: the axon with myelin sheaths around its segments, the cell body with nucleus and the dendrites.

The dendrites can be considered the reception units of the neuron receiving impulses from other neurons. The dendrites can be considered the effector apparatus

transmitting the impulses to other neurons. Many axons are surrounded by a sheath composed of fatty tissue called myelin insulating it from other axons. This tube is not continuous but consists of a number of elongated segments with small gaps in between each segment. Recordings from a single nerve cell were made to study how this neuron was able to transmit a nerve impulse. The impulse is an electrical potential or voltage that can be recorded. When at rest, the cell is not firing. The resting potential inside of the cell is negative (-70 millivolt) with respect to the outside. When the cell receives an impulse from another neuron it is aroused from rest. If the pulse is weak, nothing will happen. If the pulse is strong and passes the threshold value of 55 millivolt (mV) the existing potential suddenly collapses and for a brief moment the axon interior becomes positive relative to the outside. After a short moment of about 1 millisecond (ms) the potential returns to its resting state. This entire sequence of events is called the action potential. This action potential travels passed the axon from one segment to another, each time locally changing the potential. The reason for this phenomenon is the distribution of ions over the axon causing a difference in electrical load inside and outside the axon. During rest the inside is charged negatively due to an ion pumping mechanism transferring positively charged sodium ions (Na^+) to the outside of the axon. This imbalance is maintained during the resting potential, because the ion gates enabling transferring of ions from the inside to the outside and vice versa are closed. The action potential consists of three phases. During phase one, the axon depolarises on stimulation, which mean that the polarisation of the membrane is reduced from -70 mV towards 0 mV. Only when this depolarisation reaches the threshold level the sodium gates are opened and the ions rush in creating an excess of positively charged particles inside the axon. Phase two is when repolarisation is taking place, the gates close again and Na^+ ions are no longer going into the axon, other potassium (K^+) specific gates open and K^+ ions move from the inside of the axon to the outside restoring the resting potential. During the third phase the repolarisation continues and turns into a hyperpolarisation, where still more K^+ ions move to the outside of the axon. When this stops the segment goes back to its resting potential again. On important characteristic of the action potential is that the electrical response of the axon is not sensitive to the impulse intensity, once the impulse is at threshold level or above an action potential is elicited which is always at its maximum magnitude. Another

important characteristic is that during an action potential, a second impulse will not elicit a second action potential. This is called the refractory period.

This excitation of the axon segment produces an electric current flow to the next segment, depolarising the area and in turn causing the sodium gates to open after which the process repeats itself in that segment. This process continues along the complete length of the axon. When the action potentials reach the dendrites, the impulse is transferred to the next neuron through the release of chemical substances bridging the gap, the synapse, between two neurons. The impulse from a neuron can have excitatory or inhibitory effect on the post-synaptic neuron. An excitatory effect increases the likelihood of the post-synaptic neuron to fire, whereas an inhibitory effect decreases this likelihood. The communication between neurons does not usually involve only two neurons, but many neurons. The effect on the post-synaptic neuron is a result of the summation of all inhibitory and excitatory impulses arriving at the synapse. These electrical events can be recorded from the scalp by large electrodes that respond to the electrical activity of large populations of neurons. Scalp EEG potentials are measured as the difference between two points, one on the scalp where the EEG effects are strong and one reference point, optimally isolated from the EEG effects, like earlobes or nose tip. The EEG effects come from the neurons in the cortical surface. An estimate of the number of neurons per square mm cortex is around 10×10^5 .

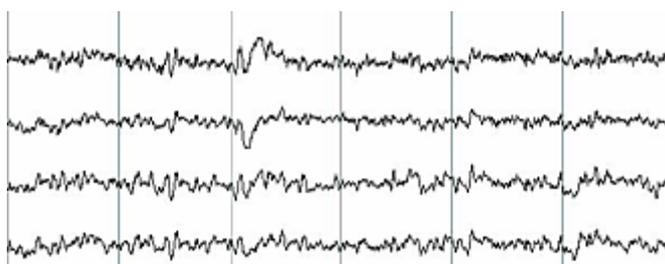


Figure 2.2. The rhythmic signal recorded from the scalp with electrodes.

With electrodes placed at several locations on the scalp a rhythmic ongoing signal is recorded which can be displayed: the electroencephalogram (Fig. 2.2). Event-related potentials (ERP) are brain responses, which are time-locked to a certain event like an auditory or a visual stimulus. These ERPs can be made visible by averaging the time-locked signal over many trials. The signal-to-noise ratio of the recording will

improve with more trials and specific waveforms in response to a certain stimulus will become visible.

2.2 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is based on the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum. Images produced by using such a non-invasive technique can be used to explore many different features of the brain like its morphology. Functional magnetic resonance imaging (fMRI) is based on the same principles and has become the preferred technique to investigate cognitive abilities (Jäncke, 2005; Toga & Mazziotta, 1996; Schild, 1992; Heinrichs, 1992; Villringer & Dirnagl, 1995).

2.2.1 The basic principles of MRI

At the basis of this measurement technique is the proton, a little particle in the nucleus of an atom, with a positive electrical charge. The protons used for MRI are parts of the hydrogen nucleus (H^+), which only has a single proton and which are abundant in the body due to the high water content of non-bony tissues. These

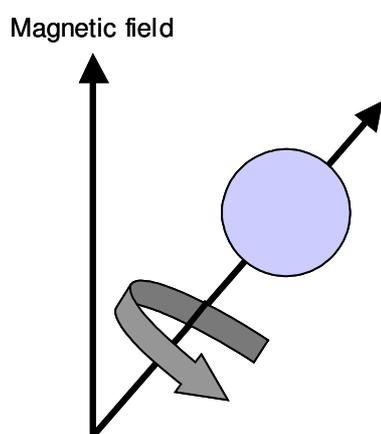


Figure 2.3. A proton spins around its own axis at a slight angle from the outer magnetic field.

protons are continuously spinning around their own axis and thereby causing an electrical current. The electrical current is accompanied by a small magnetic field. Thus, a proton can be viewed upon as a small magnet, which will orient itself to the magnetic field lines when put in a strong, externally imposed magnetic field in either a north-south or a south-north orientation.

The orientation will depend on the energy level of the proton. Slightly more than half of the protons prefer to be in a situation which costs the least energy and their preferred orientation is near parallel to the static field, the others are aligned in the opposite direction of this magnetic field. The individual protons are not actually aligned completely parallel to the direction of the outer magnetic field, but set off at a

slight angle from the direction of the magnetic field lines, where they circle around their spin-axis (Fig. 2.3). This motion is called precessing. The strength of the magnetic field force determines their precessing velocity and thus their frequency (cycles per second).

Due to the high water content in the human body there are millions of protons circling around at this velocity, but not all with the same magnetisation vector. The overall net vector of magnetisation depends on the summation of the magnetisation vectors of all protons at a certain time. For example, if there are two protons of which one is pointing into a direction with vector x,y along the direction of the z -axis (the direction of the external magnetic field) and the other one is pointing into the exact opposite direction, then the magnetic forces of these protons will also point into exactly the opposite direction. This results in a net magnetisation vector of zero or put differently, the magnetisation vectors of the protons will completely cancel each other out and looked upon from outside the object, the net magnetic result will be zero. In a static magnetic field slightly more than half of the protons become aligned with the field and the rest become aligned in the opposite direction. Therefore, the summation of the magnetisation vectors will result in a small net magnetisation effect caused by the few protons that are not cancelled out by protons oriented in the exact opposite direction. As the net magnetisation vector of the body is aligned with the direction of the z -axis longitudinal to the external static magnetic field, it is impossible to measure its intensity.

To change the orientation of the spins relative to the direction of the static external magnetic field, a rapidly alternating magnetic field at an appropriate resonant frequency in the radio frequency (RF) range is broadcasted toward the object in a line perpendicular to the magnetisation vector. Only those nuclei, which precess about their axes at the RF pulse frequency, will be affected by the pulse. The RF pulse has two effects on those protons. First, it brings those affected to a higher energy level and will be able to change their orientation from parallel to angular with the external magnetic field. This will decrease the net magnetisation vector along the longitudinal z -axis. The RF pulse also causes the protons to precess in phase in the x - y plane. With all magnetic fields of the protons oriented in the same direction, the magnetic vectors are no longer cancelling each other out, but accumulate to a new transversal magnetisation, moving along with the precessing protons (around the z -

axis). Additionally, the RF pulse increases the angle of precession of the nuclei around their axes. This increase of precession angle does not affect the direction of the net magnetisation vector (which is in the z-direction), but it does decrease the strength of the magnetisation vector, since the nuclei's spin axes now deviate more from the z-axis than they did before the pulse.

Once the RF pulse is turned off two things occur independently of each other. Over time the precession angle decreases and the strength of the net longitudinal magnetisation vector increases, since all the nuclei are gradually pointing more towards the z-direction. In other words, the angle of precession of the axes declines or relaxes back to its resting state. The index indicating the speed at which the longitudinal magnetisation relaxes, and thereby increases again, is called T1 relaxation time. The T1 relaxation time lies between 300 and 2000 ms. At the same time, the transversal magnetisation vector which increased with the RF pulse, now decreases over time. This is because the protons will slowly start to precess out of phase and will, therefore, eventually cancel each other out again. This is indexed by the transversal relaxation time, T2 and T2*, which lies around 30 to 150 ms.

The net magnetisation vector is the summation of the longitudinal and the transversal magnetisation vector, which circles, pointing upward, around the z-axis with the direction of the spin. The RF pulse causes a change in the direction of the net magnetisation vector in the direction of the x,y plane, because the longitudinal magnetisation decreases and the transversal magnetisation increases. As the net magnetisation vector is no longer parallel to the external magnetic field it can be measured. This circling net magnetisation vector induces an electrical current, which now also can be detected and recorded. When the RF pulse is turned off and the longitudinal and transversal magnetisation vectors change back to their original state, the net magnetisation becomes parallel to the outer field again and no signal can be recorded.

2.2.2 Signal location and imaging

It is important to be able to spatially locate the origin of the electrical signal. This can be obtained by introducing the object (e.g., the head) to a magnetic field which differs in strength at each point instead of a homogeneous static magnetic field. These regional differences in the static external magnetic field induce differences in the

precession frequencies of the protons and in turn the recorded electrical signals will have different frequencies and based on these frequencies coordinates can be given to the origin of the signals.

The recorded MR signal is decomposed into its basic frequencies using a Fourier transformation and the intensity of the signal per frequency is determined. With this information an image can be computed. The brain is not recorded as a whole, but in slices. Although each slice is composed of volume elements or voxels, the image itself consists of pixels where the intensity of a pixel is proportional to the MR signal intensity of the content of a voxel.

As described above the relaxation times T1 and T2 are of specific importance for the signal recorded. These times depend on what type of tissue the signal comes back from. For example, a tissue with high water contents has a long T1 and T2 times and a fatty tissue has a short T1 time and a long T2 time.

2.3 Functional Magnetic Resonance Imaging: the BOLD effect

Neural activity in the brain is associated with variations in cerebral metabolism (blood flow, volume and oxygenation), but mechanisms are still little understood. However, magnetic resonance imaging can be applied to detect some of these haemodynamic changes (Jäncke, 2005). The most frequently used fMRI method is based on blood oxygen level-dependent (Tunik, Schmitt, & Grafton, 2007) contrast, which was first described by Ogawa et al. (1992) in rodent brain studies and was later applied to generate functional images in the human brain. They have shown that changes in the level of blood oxygenation lead to a significant increase of the measured signal intensity (Ugurbil et al., 2000). The BOLD effect is a contrast mechanism which describes these changes.

The effects of performing a task are physiological and physical. At the physiological level there are two effects. Initially, oxyhaemoglobin (oxyHb) is deoxygenated, which means that the level of deoxyhaemoglobin (deoxyHb) rises. Subsequently, the deoxygenation is overcompensated by an increase in the regional cerebral blood flow, which causes the level of deoxyhaemoglobin to decrease again (Fig. 2.4.a).

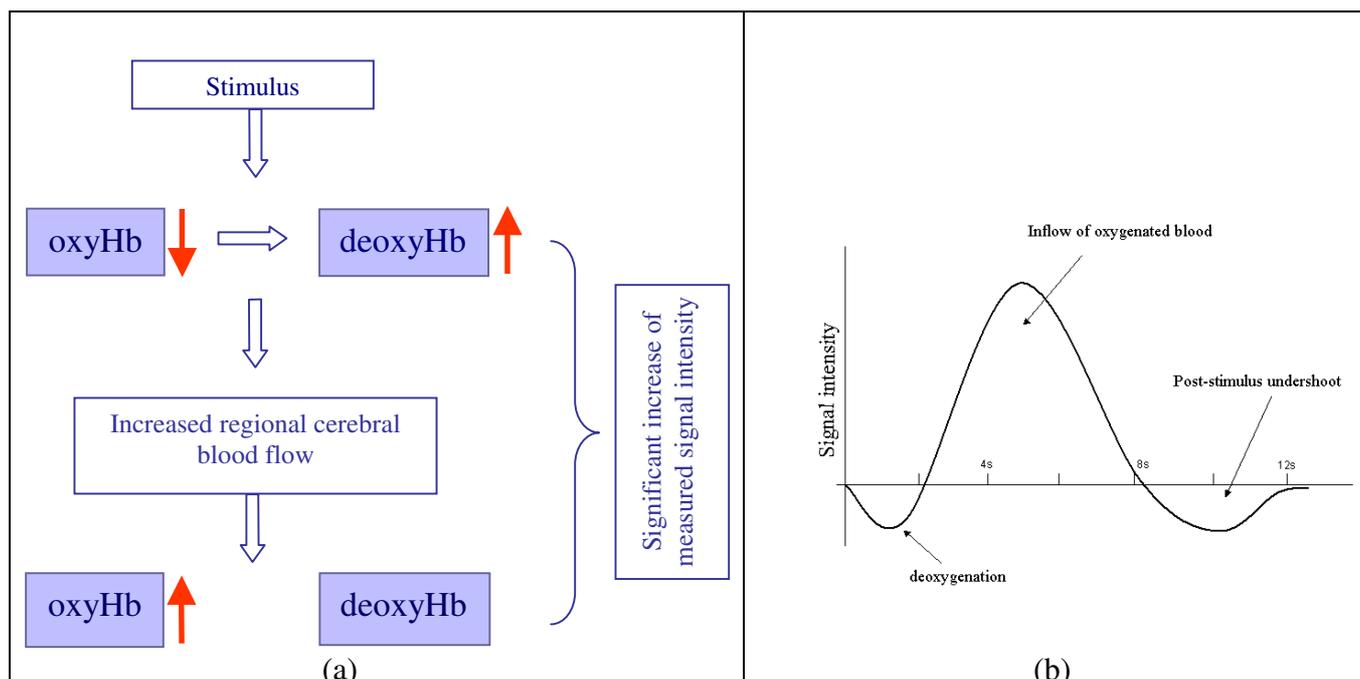


Figure 2.4. (a) The haemodynamic changes after presentation of a brief stimulus. In response to the increased cerebral blood flow the level of oxyHb increase, which results in a net decrease of the level of deoxyHb. (b) Haemodynamic response curve. The signal intensity changes in response to a brief stimulus. The initial dip is the result of local blood flow changes (deoxygenation). The positive signal results from larger scale flow changes (inflow of oxygenated blood). The post-stimulus undershoot is the return to normal flow.

To be able to describe the physical effects of these changes in oxygenation the concept of magnetic susceptibility needs to be described. Certain metals, when placed in a magnetic field experience pronounced polarisation relative to water or air. The degree of this effect is referred to as the magnetic susceptibility. Oxygenated blood contains oxygenated haemoglobin, which has diamagnetic properties and thus a small magnetic susceptibility effect. It does not significantly alter the regional magnetic field and does not affect the tissue relaxation time $T2^*$. The deoxygenation of haemoglobin produces deoxyhaemoglobin and has paramagnetic properties. It thus disturbs the local magnetic field in a region of tissue which leads to a large and observable magnetic susceptibility effect. The fluctuations in magnetic susceptibility caused by the changes in local concentration of deoxygenated and oxygenated haemoglobin, thus affects the locally observed relaxation time $T2^*$. A small local region is compartmentalised into voxels and the $T2^*$ from each voxel is the measurement extracted for constructing the fMRI contrast which determines the image intensity.

So, when in response to a local activation the regional blood flow increases and thus causes an increase in oxygenated blood, this will result in more oxygenated

haemoglobin and a relatively lower level of deoxygenated haemoglobin, creating a longer regional $T2^*$ and an increase in image intensity. The changes in haemodynamics in regions that are engaged by a task can be visualised as changes in MR image intensity (approx. 1-10%) and show differences compared to regions in a resting state. The BOLD signal after stimulation can be modelled by depicting the changes in signal-intensity in time (Fig. 2.4.b).

2.4 The differences between EEG and fMRI

Understanding the neural basis of brain functioning requires knowledge about the spatial and temporal aspects of information processing. EEG and fMRI are both non-invasive tools widely used to investigate human brain functioning. EEG measurements deliver the necessary temporal resolution, but a relatively poor spatial resolution, which is needed to identify underlying neural sources. fMRI yields highly localized measures of brain activation, with a good spatial resolution (about 2–3 mm), but a temporal resolution significantly longer than the time needed for most perceptual and cognitive processes. Utilising both tools in an investigation is particularly useful to examine both the temporal and the spatial dynamics of brain activity.

Chapter 3

Detection of visual change: an ERP study

3.1 Introduction

The human brain is exposed to a continuous stream of information from the environment, which would normally flood the system. Selective mechanisms are set in place to efficiently direct attentional resources to the processing of task-relevant information. However, the seemingly irrelevant input could still hold information with important content. Previous research on the processing of the continuous auditory information flow gave much insight into how unattended information is still monitored. Unattended or unnoticed does not equal unprocessed (Näätänen, 1992; Pazo-Alvarez, Cadaveira, & Amenedo, 2003).

Because of the limited amount of literature available on the automatic processing of visual input the phenomenon of automatic processing of irrelevant information is introduced with an auditory example. A typical example showing that the brain does monitor the environment is when a grandfather clock suddenly stops ticking. Right after it holds, one becomes aware of the sudden silence and at the same time one realises it had been ticking all along. This example elucidates, that as an essential part of its normal functioning the brain has a monitoring ability which allows for automatic detection of sudden changes in the unattended part of the auditory information stream without the need to allocate attentional resources to it. Moreover, this ability can be measured in newborns and is elicited throughout life (Alho, Sainio, Sajaniemi, Reinikainen, & Naatanen, 1990; Näätänen & Alho, 1995).

The benefit of such a system is that once the change or deviance has been detected it comes into the focus of attention which allows for further evaluation. Based upon the new information, it can then be decided whether it is necessary to modify current behaviour. Looking at the development of brain functions from an evolutionary perspective, it must be taken into consideration that such a mechanism supporting quick adaptation to new or unexpected situations may well have influenced the survival rate of our forest-hunting ancestors who were regularly faced with developing obstructions, opportunities or threats.

The brain is seen as a capacity-limited system and can be characterised in neuronal networks associated with brain functioning. It has been established that parts of a specific functional network can also play a role in other networks (Chee, Soon, &

Lee, 2003; ffytche & Catani, 2005; Mesulam, 1998; Sporns, Tononi, & Edelman, 2000; Tunik et al., 2007). Therefore it is plausible that parts of the network involved in the mechanism of automatic auditory change or deviance detection are also involved in automatic change detection in other sensory modalities (Näätänen, 1992; Nordby, Brønnick, & Hugdahl, 1996; Restuccia, Della, Valeriani, Leggio, & Molinari, 2007). Especially, when considering the importance of such mechanism for continuous and effortless interaction with the every day environment.

A further indication for the involvement of a network of areas in auditory change detection came from electroencephalographic measurements recorded during the performance on an auditory oddball task. These measurements revealed two components in reaction to the detection of change which were elicited by two different generators. A sensory specific generator is located in the auditory cortex. The second component is elicited by a frontally located generator which is associated with an orienting response (Näätänen, 1992; Näätänen, 1990; Winkler & Naatanen, 1992; Opitz, Rinne, Mecklinger, von Cramon, & Schroger, 2002). If there would indeed be an overlap between an auditory and a visual automatic detection system then visual deviancy or change would elicit a frontocentral response in addition to a sensory specific response. This would support the notion, that the frontal generator may play a more general role in the automatic detection system.

3.1.1 Visual mismatch detection

The automatic detection process is based upon cortical representation of the detected regularities, which are extracted from the information stream and are referred to as the standard (Näätänen & Winkler, 1999). It is assumed that, analogous to audition, this standard includes information stored in the visual sensory memory (Astikainen et al., 2004; Näätänen, 1992; Tiitinen, May, Reinikainen, & Naatanen, 1994). A deviant is a representation of a sudden and unexpected discontinuity in the regularity (a series of standards) in the visual information stream, which is also called deviance or change in the visual stream. From auditory studies it is known that a mismatch reaction is the result of a comparison of the memory trace of presented stimuli (the standard) with new deviating information (the deviant). In search for a visual change detection system (for a review see Pazo-Alvarez, Cadaveira, & Amenedo, 2003), a variety of designs, ranging from visual discrimination studies (e.g., Czigler & Csibra, 1990, (Stagg, Hindley, Tales, & Butler,

2004) to active (Astikainen et al., 2004) , passive (Heslenfeld, 2002; Tales, Newton, Troscianko, & Butler, 1999) and delayed response oddball paradigms, as well as, studies of intermodal selective attention (e.g., Woods, Alho, & Algazi, 1992) were used. However, not all studies succeeded to ascertain a detection mechanism for visual information (e.g., Nyman et al., 1990). To ensure that an analogue to the auditory automatic detection system was found 5 criteria were used.

3.1.2 Criteria

The Mismatch Negativity (MMN), which refers to the negative displacement of the ERP after the presentation of a deviant in a series of standards, is considered the primary electrophysiological measure of the existence of a mismatch detection system. It was proposed to call this component deviant-related component (DRC) until it could be proven that all criteria for it to be a MMN component were fulfilled, after which it could be called a visual MMN (vMMN) (Wei, Chan, & Luo, 2002). These criteria include 1) independence of attention, 2) endogeneity, 3) sensory discrimination and 4) sensory memory, but there should also be 5) associations of attention orienting (Berti & Schröger, 2003).

Independence of attention can be reached by involving the participant in a task which will force him to focus on other stimuli than the ones presented to elicit the mismatch reaction. This task could either be in the same modality or in a different modality. An example can be taken from Maekawa et al. (2005), who investigated whether changes in a windmill pattern could elicit a DRC. Their procedure included two tasks: listening attentively to a story and pressing a button when one of two visual targets appeared on the monitor. The stimuli related to the mismatch task were interspersed in the visual task. After each block, a questionnaire was filled out on the story heard to verify that the participants had been listening attentively. Additionally, the performance measures of the visual task were used to make sure the targets were attended to. By using two tasks it is assured of that the participant's attention is directed to other than the mismatch stimuli.

Another criterion is that the MMN should be an endogenous component and any possible exogenous contribution to this component due to stimulus material has to be excluded. This can be achieved by using the stimuli once in the role of the standard

and once in the role of the deviant in the paradigm. The reaction in a mismatch situation should be independent of which stimulus is presented as deviant.

The next criteria are sensory discrimination and sensory memory. Sensory discrimination refers to the fact that changes in any feature or conjunction of features of the stimulus appear to elicit a mismatch reaction, even when these changes approximate the perception threshold (Kujala, Tervaniemi, & Schroger, 2007; Näätänen, 1992). Mainly, it was thought that the magnitude of the mismatch reaction, measured by amplitude, depends on the relationship between the trace and the present stimulus and that the amplitude grows larger as the difference between standard and deviant increases. However, recently it has been postulated that the size of the mean amplitude does not represent this particular relationship, but rather the percentage of detected deviants (Horvath et al., 2008). According to Horvath et al. reduced amplitude is correlated with the lower detection rate of the deviant. The reason the amplitude is reduced is a methodical one, because the MMN is estimated from the average over many trials. When fewer deviants have been detected, less signal goes into the average MMN. One indicator that could be used to monitor the visual sensory discrimination is the N1 response (Näätänen, Jacobsen, & Winkler, 2005; Rinne, Sarkka, Degerman, Schroger, & Alho, 2006). Its magnitude changes with the presentation of even slightly different deviants. When the N1 response changes, but the mismatch response doesn't change, then the mismatch response is not based on the changed physical characteristic of the deviant stimulus, but is a result of a comparison process of stored previously presented information with the new visual input, which brings us to the fourth criterion of sensory memory.

It has been well confirmed that the auditory MMN is dependent on an established memory trace (Winkler, Schröger, & Cowan, 2001). Whether the visual MMN was also dependent on the establishment of a memory trace was debated (see also Ch.1.6). Discussed was whether the mismatch response is the result of a mere refractory process (e.g., Kenemans et al., 2003) and related to rareness of occurrence instead of change. The alternative suggestion was, that similar to auditory mismatch the information in visual sensory memory is used to make a comparison with newly presented information. Now, more and more studies have confirmed that the mismatch process is related to visual sensory memory where it is assumed that the template representing the regularities in previously presented

information is stored (Cowan, Winkler, Teder, & Näätänen, 1993; Czigler, Balazs, & Winkler, 2002; Maekawa et al., 2005; Näätänen et al., 2005; Pazo-Alvarez, Amenedo, & Cadaveira, 2004).

The last criterion is involuntary switching of attention. An auditory MMN consists of two components, one generated in the auditory cortex and one in the frontal lobes. The former is associated with feature analysis and deviance detection and the latter is associated with attention switching towards the changes taking place in the auditory environment (Näätänen, 1992). Little is known about the frontal lobe generator in mismatch (Opitz et al., 2002). Some evidence comes from studies using auditory stimuli comparing patients with focal lesions with normal subjects (e.g., Alho, Woods, Algazi, Knight, & Naatanen, 1994) in which it was shown that prefrontal lesions diminish the overall MMN amplitude. (Rinne, Alho, Ilmoniemi, Virtanen, & Naatanen, 2000) investigated in an auditory EEG and MEG study whether a time difference between temporal and frontal MMN components could be found in order to establish how the auditory cortex change-detection mechanism is connected to higher-level processes, i.e., how involuntary attention switching is carried out in the brain. Their results showed that the difference in onset time for temporal and frontal activation was significant only in the right-hemisphere data, supporting the hypothesis that some frontal areas are activated during the MMN response and that these frontal areas were activated later than the temporal auditory cortex source. They presented data providing evidence that the frontal component of the MMN is generated by a mechanism related to involuntary attention switch as it had been shown that small changes in task-irrelevant auditory stimuli elicit MMN even when the participant is performing an attention-demanding task and that these small unattended changes deteriorate task performance. Furthermore, Maekawa et al., (2005) reported that although it was impossible to measure how much of the attention was shifted to the deviant stimuli, it was observed that irrelevant deviants interfered with the primary target detection task, as was seen in the reaction time results. One possible reason why the influence of mismatch detection on the performance of the primary task is noticeable is because both seem to rely on working memory (Kimura, Katayama, & Murohashi, 2005).

To confirm all criteria listed here a series of experiments would need to be performed, to control for them all. Some criteria have already been confirmed in other

studies (Czigler et al., 2002; Kimura, Katayama, & Murohashi, 2006; Maekawa et al., 2005) and therefore the focus of the present study lay mainly on endogeneity, working memory, and independence of attention.

3.1.3 The primary task

Several investigators (e.g., Czigler et al., 2004; Heslenfeld, 2003; Maekawa et al., 2005; Stagg et al., 2004; Stagg et al., 2004; Tales et al., 1999) have demonstrated that automatic, endogenous, non-refractory visual counterparts of the auditory MMN could be recorded for changes in colour, spatial frequency and motion. The primary tasks used in these studies were diverse and elucidate that the mismatch reaction can be recorded under a variety of circumstances binding the attention.

Czigler et al. (2004) displayed a screen-centred cross throughout the task of which from time to time the length of the horizontal or vertical line alternated. The changes in length alternated unpredictably and the participant had to respond with button presses to the changes. For the passive task coloured checkerboards were presented in the upper or lower field of the screen. Heslenfeld (1998) designed an intricate study utilising a compensatory tracking task where a centrally depicted rectangle moved constantly and unpredictably to the left or the right. Through button presses the participant had to always navigate the rectangle to the middle of the screen. The mismatch task was composed of black and white vertical square wave gratings with different spatial resolution covering the background of the screen. Maekawa et al. (2005) used not only a visual task, but further captured the attention of the participant with an auditory task. The instructions were to press a button with the right thumb as soon as they recognised a target stimulus on the screen and to listen to the story presented over earphones for later evaluation. Unlike some studies presented here, the standard, deviant and target stimuli (grated windmill patterns) were all part of the same task. Stagg et al. (2004) used a target detection task with the target being a centrally displayed red square appearing in the fixation frame. The standard and deviant were either two larger rectangles or double vertical bars presented above and below the target. In the present study a 2-Choice Response Time task (2-CRT) is used with coloured square targets and it includes two levels of difficulty. The responses are given with the index finger of both hands.

3.1.4 ERP to standard and deviant

The ERPs of previous visual studies in response to the standard and deviant stimuli were mainly characterised by a Positive-Negative-Positive (P-N-P) sequence (Czigler et al., 2004; Czigler, Weisz, & Winkler, 2007; Heslenfeld, 1998; Maekawa et al., 2005; Pazo-Alvarez et al., 2004) with a negative displacement for the deviants (see Fig. 3.1). This sequence was found at the occipital and posterior temporal sites

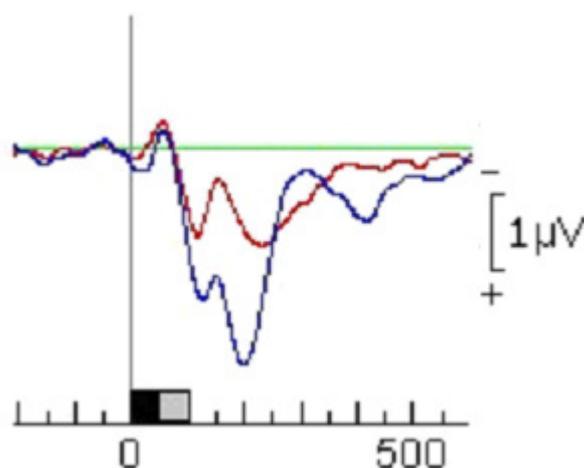


Figure 3.1. A negative displacement of the ERP to the deviant (red) in comparison to the ERP to the standard (blue).

typically starting around 100 ms after stimulus onset. Deviating from this sequence were the results from Stagg et al. (2004) and Tales (1999), which both showed a P1-N2 complex, but which was followed by a P2 for the standard in the study by Tales et al.. Also, Czigler et al., (2007) showed a P-N-P sequence for lower half-field stimulation and an N-P sequence for upper half-field stimulation.

The patterns found in the ERP responses also confirm that deviance detection can be separated from novelty detection. Novel stimuli are known to evoke a robust frontocentral N2 component (Ergenoglu et al., 2006; Kenemans et al., 2003). In contrast, the response to visual deviants in the N2 latency range (Cammann, 1990; Czigler et al., 2002; Tales et al., 1999; Tales, Troscianko, Wilcock, Newton, & Butler, 2002; Woods et al., 1992), has a scalp distribution with its maximum at the occipital region (Heslenfeld, 1998; Maekawa et al., 2005; Tales et al., 2002) and because of the different scalp distribution it is thought that the underlying neural processes are different from those involved in novelty processing.

It is possible but not necessary that the N2 is followed by a P3 component, which is suggested to be a correlate of an involuntary attention switch towards an eliciting stimulus (Deouell & Knight, 2005; Astikainen et al., 2004). In a three-stimulus paradigm with target, standard and infrequent-nontarget, but non-novel stimuli, the latter elicit a P3 with maximum amplitude over the centroparietal cortex (Polich, 2004). However, the current paradigm is not completely comparable with the three-

stimulus paradigm which may have an effect on whether a P3 is obtained in the present study.

3.1.5 Difference waves

By subtracting the response to the deviant from the response to the standard a difference wave is calculated showing an easy to read measure of the displacement of the waveform on presentation of a deviant. A change related posterior negativity (occipital and posterior-temporal) has been observed around 100-300 ms for different stimulus features like colour deviance (Czigler et al., 2004; Winkler, Czigler, Sussman, Horvath, & Balazs, 2005; Kimura et al., 2005), shape deviance (Tales et al., 1999; Stagg et al., 2004) motion direction deviance (Pazo-Alvarez et al., 2004), spatial frequency deviance (Heslenfeld, 2003) and spatial location deviance (Berti & Schröger, 2004).

Most previous studies have only reported the ERPs for the occipital and posterior temporal regions, where the clearest response were seen. Others have shown the ERPs of the frontal regions as well, but didn't perform any analysis at these sites (Maekawa et al., 2005; Stagg et al., 2004). Additionally, Kimura et al. (2006) reported a posterior positivity (P84) prior to the negative component. Several other investigations showed an anterior positivity in a similar time interval as the posterior negative component (Czigler et al., 2004; Heslenfeld, 1998; Pazo-Alvarez et al., 2004), which could serve as a further indicator for the independence of a posterior and a frontal component parallel to the two components found in auditory mismatch studies.

3.1.6 The present study

The studies presented in this chapter, although not all with positive results (e.g., Csibra & Czigler, 1991; Nyman et al., 1990) seem to warrant further investigation into the visual counterpart of the auditory MMN.

The aim is to design a paradigm suitable to establish an MMN in the visual modality. The logic of the paradigm is based on the notion that a vMMN is only elicited by visual stimuli violating a detected regularity in the visual information stream, but not by visual stimuli that are part of the currently maintained standard. According to Näätänen and Alho's (1995) model the discrimination of two successive stimuli

differing in one parameter reflects the involvement of two different neural presentations. It was proposed that an underlying neural mechanism is continuously comparing the neural representation of the current input with the representations of the past input. For auditory processing the frequently presented stimulus forms a trace in echoic memory and the sensory input from the deviant stimulus does not fit with the existing neural trace, therefore resulting in a negative deflection in the electrophysiological measures. When this is transposed to the visual modality it can be assumed that a neural representation of the frequently presented stimulus is formed in sensory memory and the sensory input of a deviant stimulus will evoke a deviant-related component in the ERP measures (Astikainen et al., 2004; Czigler et al., 2002). To further explore the idea that distinctive functional areas are involved in mismatch detection the behavioural measures are looked at, as well, since it is expected that not the occipital area but the activity in the frontal area could be modulated by the presentation of deviants.

The ERPs related to the mismatch paradigm are investigated from two perspectives. Firstly, a comparison is made between the electrophysiological reaction to the standard and the deviant marking the stages of information processing. Expected is a response with a maximum scalp distribution at the occipital and posterior temporal region in reaction to the standard as well as the deviant. Any discriminable change in the presented stimuli should become visible through studying the P-N-P complex where a negative displacement is expected in response to sudden deviance (Maekawa et al., 2005). Since only few studies have reported results at the more frontal sites this part of the study is more explorative (Kimura et al., 2006; Czigler et al., 2007). Additionally, the data is looked at from the classical perspective: the ERP elicited by the standard is subtracted from that elicited by the deviant, which results in difference wave. This provides a measure of the amplitude displacement making the change related response visible.

3.2 Method

3.2.1 The participants

Participants were right-handed male students recruited through the University of Trier. Students were excluded from participation when a history of head injury, neurological or psychiatric illness was indicated. Also, the current use of medication with known effects on the central nervous system led to exclusion. Claustrophobia or the presence of any implanted devices or metal foreign objects in the body were exclusion criteria specifically related to the imaging part of the study. Hand preference was of special importance, because it is known to be associated with the functional organisation of the brain (e.g., Pujol, Deus, Losilla, & Capdevila, 1999; Westerhausen et al., 2006). A modified version of the “Edinburgh Handedness Inventory” (Oldfield, 1971) comprising 12 questions was used to determine the hand preference for e.g., brushing hair, throwing, or opening a jar (see Appendix A). The sample consisted of 25 males aged between 20 and 36 years (mean age = 25.4, sd = 4.4). Prior to testing, written informed consent was obtained from all participants. Ethical approval for the study was obtained from an internal committee of the Centre for Neuropsychological Research at the University of Trier, where the studies were performed.

3.2.2 Stimuli and procedures

The paradigm included three types of visual stimuli: a baseline stimulus, a target stimulus and gratings. The baseline stimulus was composed of a grey background with a centrally located horizontal rectangular white frame behind the fixation cross.

For target stimuli the cross was replaced with targets of a 2-Choice Response Time task (2-CRT, see Fig. 3.2). The 2-CRT task had two levels of difficulty and four blocks of each level were presented. At the first level, the target was a small square frame in either a red or yellow colour. To avoid boredom, the red-yellow blocks were alternated with blocks using pink and blue frames. Each of the two colours was associated with a different response hand. At the second, more difficult level, two coloured frames appear simultaneously left and right from the fixation cross. One of

these frames is filled with a target colour (e.g., red or yellow) and the other coloured frame filled with a non-target colour (e.g., green).

The targets appeared with a randomised ISI of 350 – 450 ms for the duration of 16.7 ms at the first level and 33 ms at the second level². The instructions were to respond to the red and yellow coloured frames (or pink and blue) as quickly as possible with a button press of the left or right index finger, respectively.

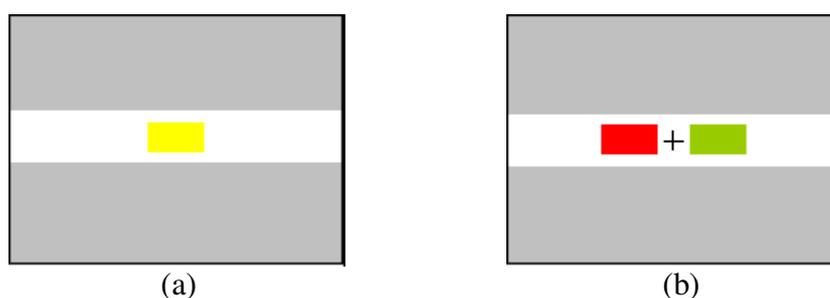


Figure 3.2. a) Example of a target stimulus at level1: The small squared frame could appear in yellow or red in one block and pink or blue in the alternate block. b) Example at level2: One frame with a target colour and one non-target frame.

The third stimulus category was task-irrelevant and consisted of black and white sine-wave gratings of either high (2.3 cpd) or low spatial frequency (0.58 cpd). These were randomly presented in an oddball-like fashion on the grey background and behind the horizontal white frame. One type of grating was used as a standard and one as a deviant with a presentation ratio 1:11 (in total 400 deviants). The role of the two gratings was changed from block to block to ensure that any outcome of this experiment would not be the result of processing differences due to stimulus material. The duration of their presentation was 16.7 ms with a variable inter-stimulus-interval (ISI) of 350 to 450 ms between two gratings. Deviants were presented in a pseudorandomised way within series of standard gratings with a randomised ISI of 4 s (mean = 3991.9 ms, = 581.2 ms). However, at least 8 standards were preceding each deviant. A total of 8 blocks, each with a duration of approximately 210 s, were presented. The software package Presentation (Neurobehavioral Systems, Albany, CA, USA) was used to implement the experiment and to record the behavioural responses. As in a typical auditory mismatch study, the

² The results from the pilot study had shown that the participants were unable to perform the task on level 2 when targets were presented with the same duration as at level 1. Due to other technical reasons the presentation was doubled for this experiment.

stimuli of the primary 2-CRT task were presented, so that these stimuli could not have given information about the presence or absence of visual changes presented as part of the visual mismatch task at any given time. Also, changes in the primary and in the mismatch task were never presented simultaneously. Additionally, the attention needed to perform the primary task most certainly discouraged from attending to the gratings presented in the background. The latter was confirmed by the statements of the participants. Only a small part of them was able to report seeing some of the change in the gratings ($\pm 10\%$ of the actual rate).

In short, the paradigm contains one apparent task (2-CRT task) and one hidden task (Fig. 3.3). Participants were kept naïve as to the purpose of the study and were only informed about the apparent task. It was explained that gratings were presented to learn more about the visual system and under which load it could still function properly.

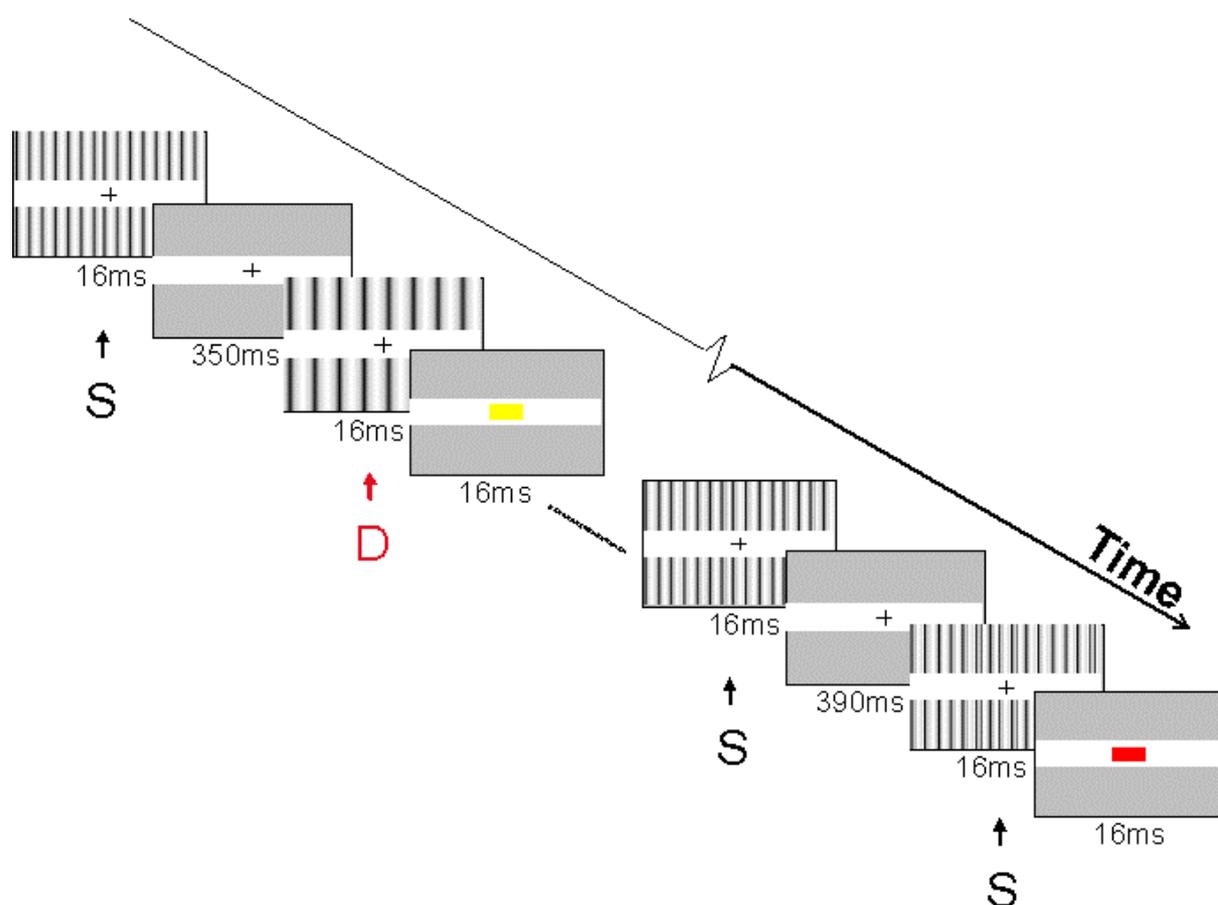


Figure 3.3. The gratings and the 2-CRT task stimuli are displayed in the order in which they were presented to the participants

3.2.3 ERP recordings

During the ERP recordings the participants were seated in a comfortable chair in a light-attenuated room. The distance of the participant to the screen was measured to be 100 cm before the start of the recordings. The ERP was recorded with 16 Ag/AgCl electrodes mounted in an elastic cap (easycap, Falk Minow Services, Munich, Germany) at the standard 10-20 positions F3, Fz, F4, C3, Cz, C4, T7, T8, P7, P3, Pz, P4, P8, O1, Oz and O2 referenced to Cz. A ground electrode was placed on the forehead. Impedances of all electrodes were kept below 5 k Ω . The signals were digitised with an analogue band-pass filter of 0.5 to 70Hz and recorded with a sampling rate of 500Hz. The vertical eye movements (VEOG) were recorded between two Ag/AgCl electrodes, affixed on the infra and supra orbital sites in line with the pupil of the left eye. The horizontal eyemovements (HEOG) were recorded between two electrodes placed on the outer canthus of each eye. Recording was performed by BrainVision Recorder software (Brain Products GmbH, Munich, Germany).

For offline preprocessing of the data the BrainVision Analyzer package (Brain Products GmbH, Munich, Germany) was used. The signal was re-referenced to mathematically linked ears and band-pass filtered between 0.1 and 35 Hz. For later statistical analysis epochs of 500 ms were extracted time-locked to the onset of the standard and deviant grating. The first 100 ms were prior to stimulus onset and served as a pre-stimulus baseline. After automatic inspection, only artefact-free trials were used for averaging.

3.2.4 Data quantification and data reduction

3.2.4.1 Behavioural performance

In order to characterise the degree of attention modulation involved and accuracy of the participant's performance, reaction time (RT) and error percentages were obtained. RTs were considered valid for analysis when they were within a time window of 150 to 750 ms after stimulus presentation. Faster reactions were considered anticipation errors and slower reactions were considered to be omissions. The mean reaction time on the 2-CRT-task was calculated under two conditions. The first condition can be described by a sequence where a deviant grating was

presented immediately before or after a target, but before the participant made a response (sequence examples: deviant–target–reaction or target–deviant–reaction). The second condition can be described by the sequence where a minimum of 6 standard gratings had been presented before the 2-CRT target and no deviant grating was presented between target and response. The accuracy was measured by the percentage of false responses under the two conditions.

3.2.4.2 Processing of ERP data

The use of an oddball paradigm resulted in an inequality of the number of trials per condition. Stimulus-locked average ERPs to the gratings were calculated using approximately 125 deviant and an equal number of randomly chosen standard trials per condition. Peak detection for the P1, N1 P2 and N2 was performed for the midline electrodes Fz, Cz, Pz and Oz. The maximum recording site for P1, N1 and P2 was Oz, while that of N2 was Cz. In addition, a difference related response was obtained by subtracting ERPs elicited by the standard from those elicited by the deviant. For statistical analysis amplitude measures (area under the curve) were extracted for five time intervals (T1 to T5) with negative measures expressing that the value of the deviant is larger than that of the standard (Beauchemin & de Beaumont, 2005). The five time intervals chosen based on the peaks seen in the average ERP were: 60–100ms, 100–140 ms, 140–180 ms, 180–240 ms and 240–300 ms.

3.2.4.3 Statistical analysis

Based on previous research it was expected that in reaction to the occurrence of a deviant two components could be found (Näätänen & Teder, 1991): The first is an early, modality specific component generated by the so called computational system and a second frontocentral component originating from the so called amplification system subjective to attentional modulation. The dependent measure was an area measure computed from the ERPs elicited by the standard and deviant stimuli presented in the background of the primary choice response time task. Two groups of channels were analysed using rmANOVA, where the midline group represented the channels Fz, Cz and Pz and the posterior group represented the Oz, P7 and P8 (Heslenfeld, 2002; Tales et al., 1999). The factors defined for the repeated measures ANOVA were Level, Colour, Probability and Channel. Level represents the difficulty level of the primary CRT-task (easy, difficult) and Colour (red/yellow or pink/blue

combination) represents another feature of the primary task. Probability represents which role the grating has in the paradigm: standard or deviant. The analysis was performed for T1 to T5 to capture any reaction to the presentation of a deviant stimulus. The analyses aimed to investigate the reaction to the two different gratings based on their role in the paradigm: standard stimulus or deviant stimulus and the effects of the primary task features on the processing of these gratings. For all analyses Greenhouse-Geisser corrections were made when sphericity assumptions were violated. Three of 27 participants were excluded from analyses because of the excessive artefacts in their ERP recordings.

To describe the deviant-related components under which the MMN was expected, difference waves were calculated by subtracting the standard ERP from the deviant ERP. This visualises the measure of displacement of the ERP on presentation of the deviant. On basis of its known negative polarity and typical latency range a possible MMN-like deflection can be identified from the grand averaged waveforms at the posterior channels. Also, a later positive deflection as described by e.g., Kimura, 2006 might be identified in the data

3.3 Results

3.3.1 Behavioural data

The mean RT in condition 1, response in a sequence with deviant, was 419.47 ms (sd = 35.23 ms) with an error percentage of 6.77 (sd = 6.61). In condition 2, response in a sequence with standards alone, the RT was 411.24 ms (sd = 48.78 ms) and the error percentage was 8.36 (sd = 7.63). Paired t-tests showed a small but significant difference, $t(.04, 22)=-1.8$ between the RTs when compared for the two conditions, but no difference was found for the error percentage, $t(.13, 19)=1.15$.

3.3.2 Effects of visual stimuli

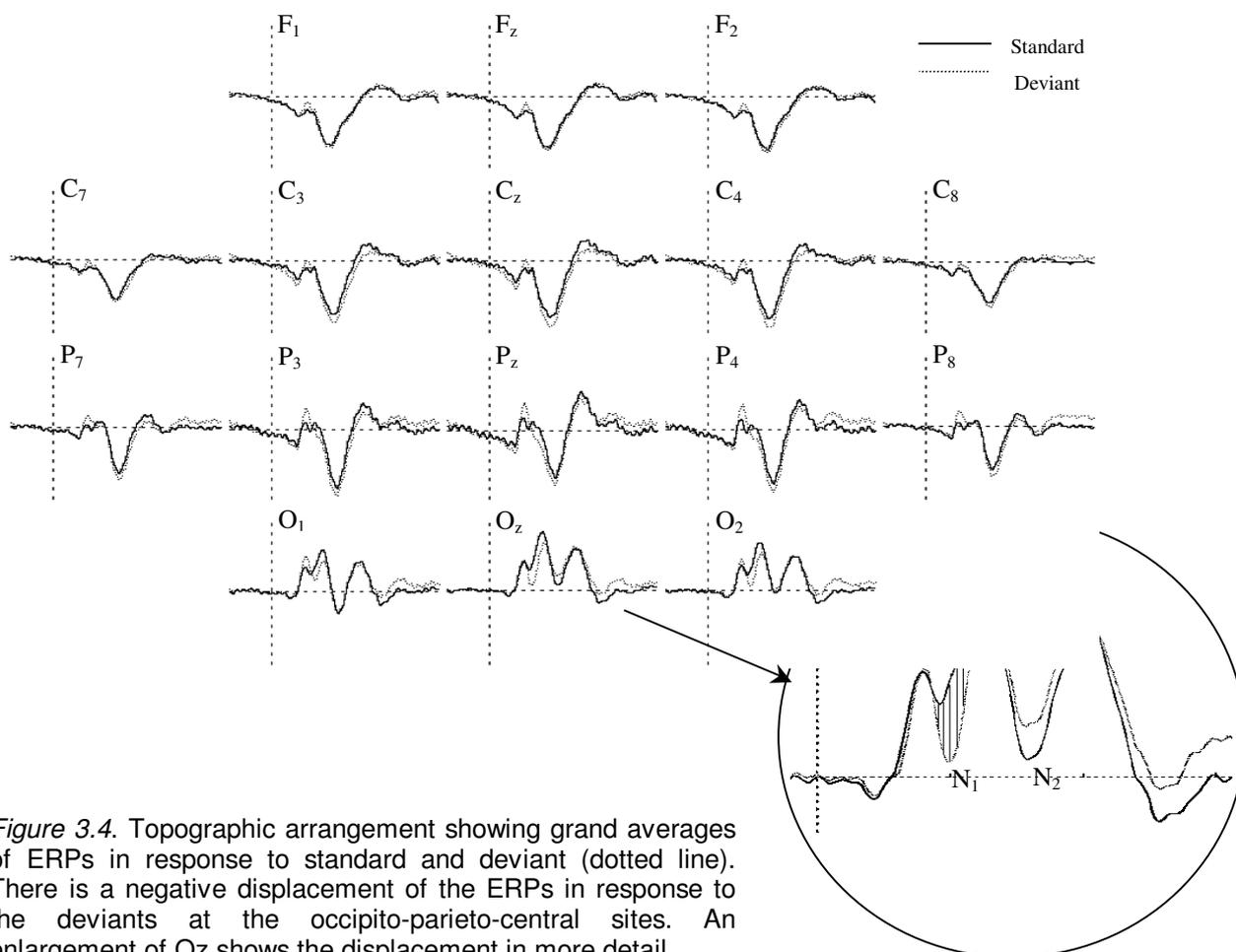


Figure 3.4. Topographic arrangement showing grand averages of ERPs in response to standard and deviant (dotted line). There is a negative displacement of the ERPs in response to the deviants at the occipito-parieto-central sites. An enlargement of Oz shows the displacement in more detail

In Fig. 3.4 the ERPs in response to the standard and deviant gratings are displayed and a general response pattern could be distinguished on the basis of the waveforms. At the occipital sites for both standard and deviant a similar P-N-P-N pattern could be distinguished and were named P1, N1, P2, N2, respectively. A more negative deflection to the deviant can already be identified starting at the downward slope of the P1 up to the peak of the P2. At the parietal, central and frontal sites a P1 and N2 could be distinguished with the reaction to the deviant slightly more positive for the P1 and more negative for the N2 than to the standard stimulus. The N2 component had a maximum at Cz. A summary of peak amplitudes and latencies of the P1, N1, P2 and N2 in the ERP elicited by the standard and deviant stimuli is shown in Table 3.1 below.

Table 3.1. Mean amplitudes (μV) and latencies (ms) of the main ERP components recorded at the maximum sites Oz or Cz. ($n=24$) Values are expressed as means ($\pm\text{SD}$)

	standard stimulus		deviant stimulus	
	Amplitude	Latency	Amplitude	Latency
P ₁	1.74 (± 3.05)	76.57 (± 12.36)	2.68 (± 2.90)	80.19 (± 7.21)
N ₁	-1.38 (± 2.51)	93.80 (± 11.70)	- .29 (± 2.92)	96.86 (± 7.84)
P ₂	4.58 (± 3.39)	131.05 (± 12.86)	4.26 (± 2.66)	125.70 (± 15.26)
N ₂	-4.94 (± 1.79)	148.81 (± 12.38)	-4.77 (± 1.77)	151.00 (± 18.66)

3.3.3 The reaction to visual change: an ERP analysis

In Table 3.2 the significant results of the repeated-measures ANOVAs for the standard and deviant ERP at the channels P7, Oz and P8 are displayed for each of the 5 time intervals (T1 to T5). The table content shows how the effects change over time and described in more detail below.

Table 3.2. An overview of the significant effects from the rm-ANOVA at the posterior sites for each time interval. Indicated are the F-values, the significance levels and at which factor level the effect was found. C1=red/yellow, C2=blue/pink, De=deviant, St=standard, E=easy level and D=difficult level.

	T1	T2	T3	T4	T5
Level					
Colour		F(1,20)=5.94 ⁺ C1>C2			
Probability					
Channel	F(1.68, 3.91) =17.73** Oz	F(1,20)=39.53** Oz		F(2,20)=17.10** Oz	F(2,20)=19.05** Oz
Ch x L					
Ch x Co					
Ch x Pr					
L x Pr		F(1,20)=6.18 ⁺ De, E>D			
Co x P					
Co x L					F(1,21)=5.77 ⁺ E.C1>C2.D.C1=C
Ch x L x P			F(2,20)=4.45 ⁺ P7P8. E>D		
Ch x C x P			F(1.7,36.33)=5.07 ⁺ Oz. C1>C2		
Co x L x Pr					
Ch x Co x L x Pr					

Note: + = $p < .05$, * = $p < .01$, ** = $p < .001$

The largest response to both types of gratings was seen at Oz with an exception for T3. The first effect of Probability, in interaction with Level, appeared in T2 indicating a larger response to the deviant in the easy condition than in the difficult condition, whereas there was no difference for the standard grating. In T3 the effect for Level x Probability was no longer significant at Oz, but was still visible at P7 and P8. In T5 the main effect of Probability showed that on presentation of a deviant a larger response was elicited than on presentation of a standard.

In T2 there was a main effect of Colour where in the red/yellow condition there was a larger response to the gratings than in the pink/blue condition. Also in T3 an effect of Colour on the processing of the gratings was found: At Oz the response to the deviant was larger in the yellow/red than in the pink/blue condition. In T4 there is no longer an effect of colour on the processing of the gratings. However, the responses at P7 were larger in the red/yellow condition than in the pink/blue condition. And in T5 the interaction Level x Colour showed that at the easy level there was a larger response in the yellow/red condition. This effect was not present in the difficult condition.

In Table 3.3 the results for the rm-ANOVA performed at the midline electrodes Fz, Cz and Pz are displayed. For each time interval the significant effects are indicated and are described below, as well.

Table 3.3. An overview of the significant effects from the rm-ANOVA at the midline channels for each time interval. Indicated are the F-values, the significance levels and at which factor level the effects were found. C1=red/yellow, C2=blue/pink, De=deviant, St=standard, E=easy level and D=difficult level.

	T1	T2	T3	T4	T5
Level		F(1.,20) =7.41** E>D	F(1,21)=9.10* E>D		F(1,21)=5.15+ E<D
Colour	F(1,20)=2.93+ C1>C2				
Probability					
Channel					
Ch x L	F(2,19)=3.65* Fz, E>D				
Ch x Co					
Ch x Pr		F(2,19)=6.84* Cz, De>St	F(2,20)=6.18** CzPz,De>St		
L x Pr					
Co x P					
Co x L					
Ch x L x P					
Ch x C x P				F(2,20)=6.88+ Cz, St. C1>C1	
Co x L x Pr					
Ch x Co x L x Pr					

Note: + = $p < .05$, * = $p < .01$, ** = $p < .001$

The course the effects take over time at the midline electrodes showed that the responses to the gratings were positive. In the easy condition they were larger than in the difficult condition for the first three time intervals. In T1 this was significant only at Fz and in T2 and T3 also at Cz and Pz. However, in T5 the area measures in the easy condition were smaller than those in the difficult condition.

Probability had an effect at Cz in T2 and at Cz and Pz in T3 with a larger response on the deviant than on the standard grating. However, in T4 this effect disappeared.

A main effect of colour was found in T1 with a larger response of both gratings in the red/yellow condition when compared to the pink/blue condition. In T4 an interaction effect was found with Channel and Probability showing that when a standard was presented there was a larger response at Cz in the yellow/red condition than in the pink/blue condition. There was no such effect on the processing of the deviant.

3.3.4 The reaction to visual change: Mismatch Negativity

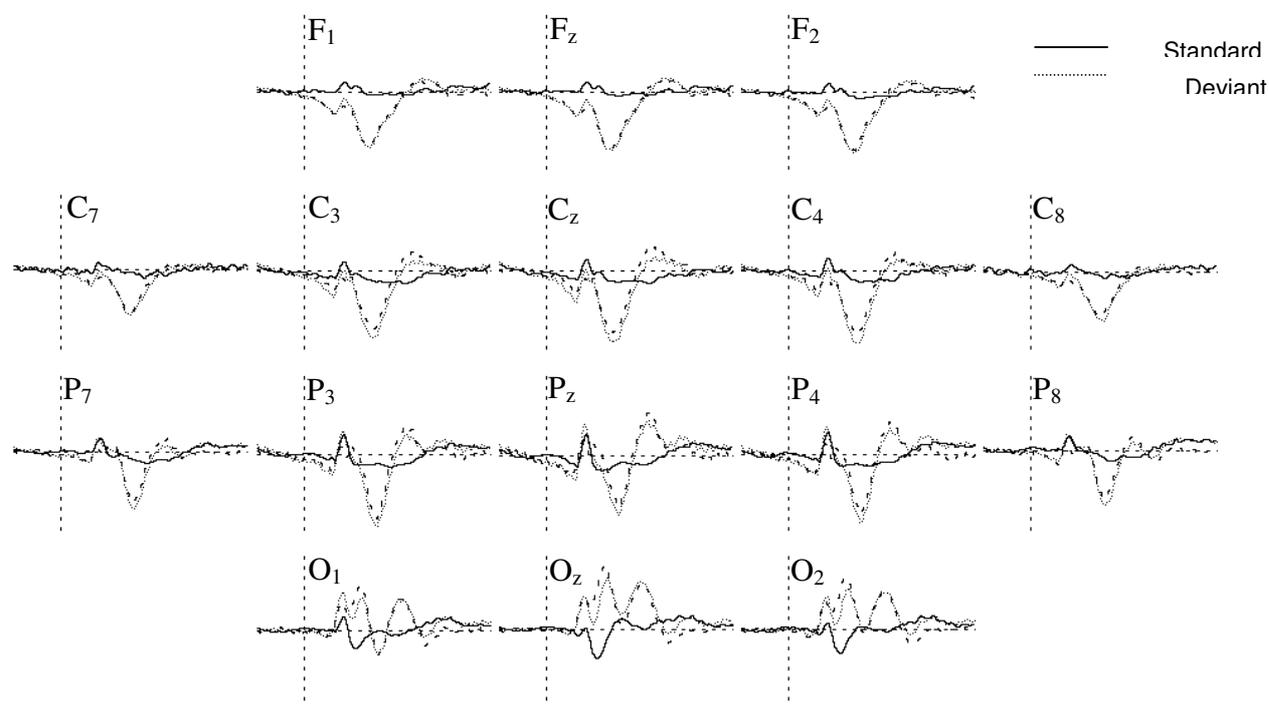


Figure 3.5. Topographic arrangement showing grand averages of ERPs in response to standard and deviant (dotted line) and added is the calculated difference wave. There is a negative displacement of the ERPs in response to the deviants at the occipito-parieto-central sites.

In Fig. 3.5 the ERP responses to standard and deviant as well as the calculated differences wave are displayed. A difference can be seen between the occipital channels and the other channels. At Oz a very clear waveform can be distinguished with a large negative displacement (mean amplitude $-1.8\mu\text{V}$, mean latency 108 ms) followed again by a smaller positive displacement (amplitude $.67\mu\text{V}$, mean latency 160 ms), which is not present at O1 and O2. At the parietal and central sites a positivity is followed by a long stretched negativity, which is seen clearest towards the midline channels. At Fz the least displacement is seen and only two early positive peaks become visible. It seems that posterior the largest response was seen at Oz and frontocentral at Cz.

3.4 Discussion

In the present study a visual automatic detection system was searched for. The first aim of the study was to design a paradigm suitable to establish a MMN in the visual modality. Based on previous research it was expected that in reaction to the occurrence of a deviant two components could be found (Näätänen et al., 1991;

Pazo-Alvarez et al., 2003; Tales et al., 1999): The first component was an early, modality specific component followed by a second component in the frontocentral region.

The present data showed that the largest response to the irrelevant visual gratings occurred at the occipital cortex at Oz between 100 and 140 ms after presentation. It indicated that the irrelevant visual information was processed, even though it wasn't part of the primary task (Näätänen, 1992). Moreover, the larger negativity in this time interval seems to support the existence of a mismatch detection system responding to a change or deviance in a repetitive series of standard stimuli. Additional support comes from other studies where it has been reported that such a displacement does not occur when the deviants are presented in a series of stimuli from which the standards have been removed (e.g., Astikainen et al., 2004; Maekawa et al., 2005).

Results from visuo-motor investigations on change blindness fit well with the observations on the unintentional experience of changes in the present study. If a target was displaced during a saccade, the hand of the observer reaching towards it would correct its trajectory, even when the observer never consciously noticed the displacement. So, the occurrence of a change can be registered and acted upon, without being accompanied by an actual visual experience by the observer. In the present study the changes had been observed by some of the participants, but never to the degree to which they were presented (Rensink, 2000).

Additionally, evidence was found for a frontal component in the change detection process. In the same interval where at the occipital channels a negative deflection was found, a positive response to the deviant and standard gratings was found in the central area. In the time intervals from 100 to 180 ms the deviant elicited a larger response than the standard. This was taken as support that also at a higher processing level the system is able to differentiate between a deviant and a standard stimulus.

The data confirm that already at a very early processing level deviant and standard gratings each evoke a specific response. These responses occurred irrespective of the spatial frequency of the gratings, since the high and low spatial frequency gratings were both used in the role of standard and deviant (endogeneity criterion), and could so be related to deviancy. Also, these responses resembled the response

described for automatic deviance detection in the auditory information processing: A modality specific response at the occipital cortex and a deviancy related response at the central area (Näätänen, 1992).

One of the criteria for mismatch is the independence of attention. It was found at Oz that the negativity was larger during the easy primary task than during the difficult task for deviant stimuli. However, there was no difference in amplitude for standard stimuli. At the frontocentral sites all responses were larger under the easy condition when compared to the difficult condition. It therefore seems likely that the level of distraction caused by the difficulty of the primary task has an influence on the underlying system automatically processing irrelevant visual information, but does not abolish the processing of irrelevant information nor the occurrence of the mismatch response.

At the occipital electrode only the processing of the deviants seemed to be influenced by task-load of the primary task. However, at the other midline channels the processing of both stimuli was related to reduced amplitude measures. This could indicate that the attentional resources available have a specific effect on deviance processing at the occipital site and a general effect on the processing of irrelevant information at the frontocentral locations.

Additionally, slower RTs on the 2-CRT task were found when a deviant grating appeared in a series of standards. The task irrelevant changes in the visual background may be related to distinct behavioural distraction effects on the 2-CRT task. However, it seems that the distraction is not enough to induce erroneous behaviour, since the error percentage was not related to the appearance of a deviant. Considering that task load had an effect on the response to stimulus change at an unattended location and a slower RT was found on the processing of a deviant grating, it can be argued that both processes rely on the same underlying neural process which could be working memory (Berti et al., 2003; Czigler et al., 2004; Kimura et al., 2005; Maekawa et al., 2005; Rinne et al., 2006; Rinne et al., 2000).

It was postulated that the mismatch detection is the result of processing which involves a network of functional areas. The difference in response pattern at Oz when compared to the other midline electrodes and the dissociation of the responses at the visual specific cortex and the frontocentral locations based on the effect of

task-load seem to indicate that indeed multiple functional areas are involved in the automatic processing of irrelevant visual information. (Czigler et al., 2004; Näätänen et al., 1991; Rinne et al., 2000; Rinne et al., 2006).

The calculated difference wave at Oz showed a negative deflection independent of which grating was presented as a deviant. This component seems to be comparable to the negative component found in auditory mismatch studies and could be the visual MMN (Maekawa et al., 2005; Wang, Kuroiwa, Li, Wang, & Kamitani, 2001). At the midline channels a positivity was found which was followed by a stretched negativity seemingly with two peaks. These two negative peaks confirmed findings from previous study by Wang et al. (2001). Again the differences between the response at the occipital channel and the other midline channels seem to support the existence of two processes taking place in visual change detection. Moreover, these could be seen as two stages of processing (Czigler et al., 2004).

The relationship between the colours used in the primary task and the processing of the deviant revealed that in the red/yellow condition the ERPs were larger. It needs further testing to find out why the red/yellow condition had a different effect than the pink/blue combination. The difference could be due to a difference in colour processing, but also it could not be completely excluded that one combination was easier to process than the other.

To summarise, the following main conclusions could be drawn. Firstly, the human brain appears capable of detecting changes in a series of repeated irrelevant visual stimuli during the performance of another demanding visual task. An occipital and a central component could be associated with the detection of change. Secondly, the level of distraction caused by the difficulty level of the primary task seemed to have an influence on the underlying system involved in the automatic processing of irrelevant visual information. And lastly, considering that primary task difficulty had an effect on the response to stimulus change at an unattended location and a slower RT was found on the processing of a deviant grating, it can be argued that both processes rely on the same underlying neural process which could be working memory.

Chapter 4

The BOLD response in a visual change detection task

4.1 Introduction

Mismatch negativity (MMN) is a component of the scalp-recorded ERP elicited by occasional unexpected deviances or changes in a series of standards. MMN is elicited even when the subject is engaged in a demanding task and not attending to the stimuli (Näätänen, 1992). In Chapter 4 the neural activity recorded during the visual mismatch detection task was discussed. An early sensory specific mismatch reaction of the brain to the deviant stimulus could be established in the occipital cortex, the visual MMN, followed by a central component, which could be related to the attentional demands of the primary task.

It is postulated here that this frontocentral component could be the result of activity in a functional neural network involved in processing the detection of a mismatch in the primary cortex. This notion parallels the model introduced by Näätänen where a modality specific component is generated by the computational system and followed by a frontal component originating from the so called amplification system subjective to attentional modulation (Näätänen et al., 1991). Support for this notion comes from an EEG and MEG study by Rinne et al. (2000). They discovered that the frontal activation followed the activation of the sensory specific generator in the auditory cortex. This was an important step in establishing how the primary change detection system could be connected to higher-level processes. It was suggested that areas like temporo-parietal junction (TPJ), inferior frontal cortex, superior frontal gyrus, and cingulum might participate in the network generating the frontal component of the MMN (see also Celsis et al., 1999; Pugh et al., 1996).

A complex fMRI study by Downar et al. (Downar, Crawley, Mikulis, & Davis, 2000) provided further leads to which areas were responsive to sudden changes and could be part of the functional network underlying the frontal component of mismatch detection. The study involved a mixture of changes in visual, auditory and tactile stimuli. Changes were introduced within one modality as well as between modalities. A distributed, multimodal network responsive to changes in all three sensory modalities was revealed, which comprised the TPJ, inferior frontal gyrus, insula and left cingulate area and supplementary motor areas (SMA). Visual-specific areas included bilateral visual association cortices including the middle occipital gyrus.

Patients with neglect showed a deficit in reorienting attention toward new unexpected stimuli in the visual field opposite to the lesion. Lesions in the TPJ were found to be associated with this deficit (Corbetta, Kincade, & Shulman, 2002; Rorden, Fruhmann, & Karnath, 2006). Additionally, patients with parietal lesions can detect visual stimuli in the contralesional field when cued, but have difficulty detecting these stimuli when attending to other locations. They cannot disengage the focus of attention and reorient to unattended stimuli in the neglected field. This deficit seemed more strongly related to right parietal than left parietal lesions and specifically to TPJ. Based on these findings it was suggested that this area might be important for reorienting the focus of attention toward visual stimuli appearing at unattended locations (reorienting hypothesis; Corbetta et al., 2000). It seems likely that the TJP becomes activated in the mismatch detection task when a deviant is processed correctly.

An underlying mechanism for change detection is thought to be working memory. It is generally accepted that working memory allows for the encoding and storing of information for short periods of time, thus making it available for manipulation and for the active guidance of behaviour. In previous fMRI studies a distributed network of cortical areas engaged during working memory tasks was located including areas in the dorso- and ventrolateral prefrontal cortex (DLPFC, VLPFC) and the superior and inferior parietal lobule (Cohen et al., 1997; Smith & Jonides, 1999; Fletcher, Shallice, & Dolan, 2000). Additionally, it is thought that working memory is involved in the comparison process of the existing neural trace of the regularly occurring stimuli with the new input (Berti et al., 2003; Czigler et al., 2004; Kimura et al., 2005; Maekawa et al., 2005; Rinne et al., 2006; Rinne et al., 2000). Therefore, it is expected that these regions could also become activated in the present mismatch detection task.

The present study aims to find brain regions involved in the processing of stimuli from the visual mismatch detection paradigm. The literature introduced here originates from auditory and visual studies. However, based on the notion that parts of the network of brain areas involved in mismatch detection are shared between the modalities it is expected that outside the sensory specific visual regions activations can be found in areas that were also activated in studies investigating auditory or sensory modalities (e.g., Downar et al., 2000). Likely candidate regions are the TPJ, inferior and superior frontal cortex, cingulum, SMA and insula.

4.2 Method

4.2.1 Participants

Participants were right-handed male students recruited through the University of Trier. Students were excluded from participation when a history of head injury, neurological or psychiatric illness was indicated. Also, the current use of medication with known effects on the central nervous system led to exclusion. Claustrophobia or the presence of any implanted devices or metal foreign objects in the body were exclusion criteria specifically related to the imaging part of the study. Hand preference is known to be associated with the functional organisation of the brain (Pujol et al., 1999; Westerhausen et al., 2006). Due to the explorative character of this fMRI study it was important to reduce the variability from non-task related parameters like handedness. A modified version of the “Edinburgh Handedness Inventory” (Oldfield, 1971) comprising 12 questions was used to determine the hand preference (see Appendix A). The sample consisted of 17 males aged between 20 and 36 years (mean age = 26.6, sd = 4.9). Prior to testing, written informed consent was obtained from all participants.

4.2.2 Stimuli and procedure

The paradigm included three types of visual stimuli, a baseline stimulus, target stimuli and stimuli related to the mismatch task. For a precise description of these stimuli it is referred to Chapter 3 (see also Fig. 3.2 and Fig. 3.3). In each of the 6 experimental runs a total of 115 2-CRT task stimuli appeared in the foreground with an ISI of 350 to 450 ms and the stimulus duration was approximately 17 ms (easy condition) or 33 ms (difficult condition). The mismatch stimuli (per experimental run 460 standards and 20 deviants) appeared in the background. The standard was presented with an ISI of 350 to 450 ms for 17 ms. In between two deviants were 23 to 46 standards to avoid attenuation of the stimulus-specific fMRI signal (fMRI adaptation or “repetition suppression”).

It was requested to respond as quickly as possible to the coloured target stimuli (red or yellow, pink or blue) with a right or left button press with the right index finger in half of the experimental runs. In the other half the participant had to respond with the left index finger. Visual stimuli were delivered to the participant via a beamer that

projected on a small screen right outside the scanner. A mirror was mounted on the head coil allowing the participant to see the images on the screen. The software package Presentation (Neurobehavioral Systems, Albany, CA, USA) was used to implement the experiment and to record the behavioural responses. Changes in the primary and in the mismatch task were never presented simultaneously.

Summarised, the paradigm contains an apparent task (2-CRT task) and a hidden mismatch detection task. Participants were kept naïve as to the purpose of the study and were only informed about the apparent task. It was explained that gratings were presented to learn more about the visual system and under which load it could still function properly.

4.2.3 MR Image acquisition and processing

The MR scanner used for imaging was a 1.5 T Philips Gyroscan Intera Magnetic Resonance Tomograph (Philips Medical Systems, Best, Netherlands) with a standard head coil. As part of the current study three types of measurements were performed. An orienting sequence to locate the head in the coil was followed by a high-resolution anatomical sequence and the functional MRI recordings.

A high-resolution anatomical recording with coronal view was acquired from each subject with a T1-weighted Fast Field Echo sequence. The scan parameters for this sequence were repetition time (TR) = 12.02 ms, echo time (TE) = 400 ms, field of view (FOV) = 256 x 256 x 160 mm. Utilising linear interpolation the individual data were reconstructed to a resolution of 256 x 256 x 160 mm, which resulted in isotropic voxels of 1.0 mm³. For the functional MRI recordings an echo planar T2*-weighted scanning sequence was used starting with 5 dummy scans to ensure steady-state magnetisation (32 slices of 4 mm thickness, no gap, TR = 3000 ms, TE = 50 ms, flip angle 90°, FOV 256 x 256 x 128 mm, matrix 64 x 64 x 32 resulting in a voxel size of 4 x 4 x 4, 196 volumes)

Pre-processing of the raw fMRT data was done to correct for non-task related variability using SPM2 (Wellcome Department of Imaging Neuroscience, ION, UCL, London, UK) and included 1) realignment, which aims at correcting motion in fMRI sequences, 2) slice time correction to the middle slice, which is performed to correct the fMRI time series data for the differences in image acquisition time between the

slices within a TR (sinc interpolation) 3) normalisation, which refers to spatial normalisation of the data in a standard space (EPI image) and enables later averaging across subjects and 4) smoothing, which is the application of a Gaussian kernel (8 mm FWHM) increases the signal-to-noise ratio and reduces the number of comparisons.

Once the data was prepared, a two stage procedure was applied (Friston, Holmes, Price, & Worsley, 1999; Holmes & Friston, 1998). Firstly, at an individual level fMRI models were fitted (first-level analysis). For this purpose the data was linked to the experiment using the marker file containing information on time of occurrence, duration of stimulus and response, as well as trigger times for each scan. The data was fitted to an HRF function. Contrasts were calculated for the different stimuli, i.e., standard vs. baseline and deviant vs. baseline, and the estimated stimulus specific activation was written out as images. To extend inferences to the population (second-level analysis) the subject activations must be treated as random effects allowing for inferences on the population mean activation. This second-level analysis or random effects modelling was performed to assess the images using a one-sample t-test, a voxel-wise significance threshold of $p < .001$ or a threshold of $p > .01$ extended with a cluster size of 20 contiguous voxels was applied. Thus estimated activations were assessed against their variance across subjects. The BOLD response to stimuli could only be seen when there was a significant increase (or decrease) of the measured signal intensity. The images were superimposed on a mean image of all normalised structural data. Four of 17 subjects were excluded from analysis due to pulse-related artefacts in the data.

4.3 Results

4.3.1 Localisation of the activation

Three comparisons (standard-baseline, deviant-baseline, and deviant-minus-standard) were performed to assess group differences in location of activation across task condition. In Fig. 4.1 below, activation maps are shown, (corrected threshold $p = .001$, cluster size = 20) for the comparison of the deviant to baseline. It revealed significant activation in the occipital cortex, superior parietal lobe, premotor areas, inferior frontal area, thalamus and insula.

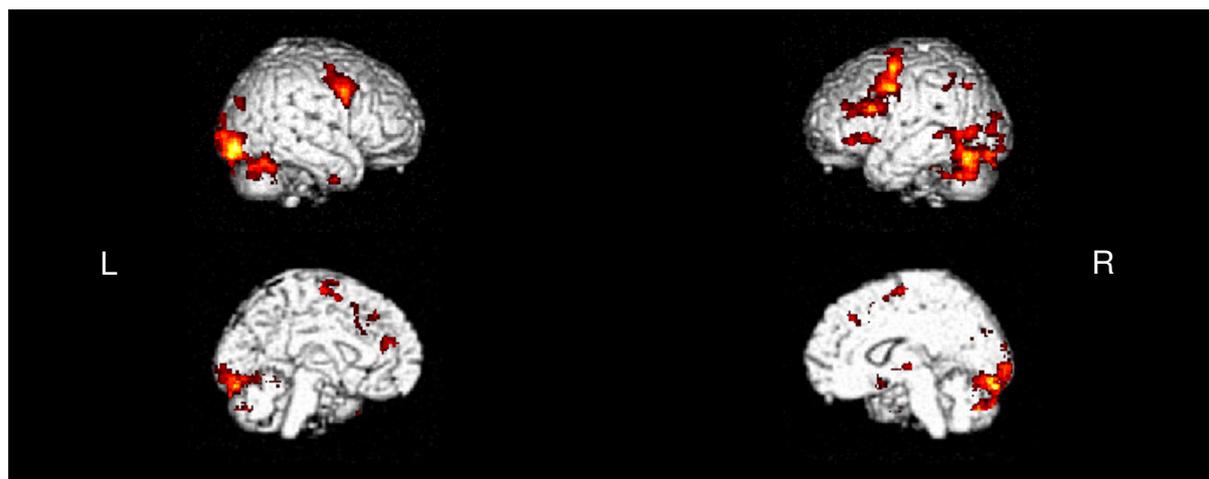


Figure 4.1. Brain regions activated by the deviant stimulus in the visual mismatch paradigm. The activated regions are derived from data of all 13 subjects. The regions are superimposed on the mean image derived from the structural data of all subjects. The anatomical images follow neurological conventions with the right hemisphere on the right side of the image. The colour scale reflects the value of the statistics (yellow high t-value, red low t-value).

In Figs. 4.2 and 4.3 the regions derived from the comparison deviant-minus-standard are displayed. In Fig. 4.2 the regions are shown which produced more activation related to deviant processing than to processing of the standard. The activation pattern was mainly not symmetrical. In the inferior occipital area the activation was stronger on the left than on the right side (Fig. 4.2.a). The activations in the inferior frontal gyrus (rIFG), thalamus and insula were only visible on the right side (Fig 4.2 c, d, e, f).

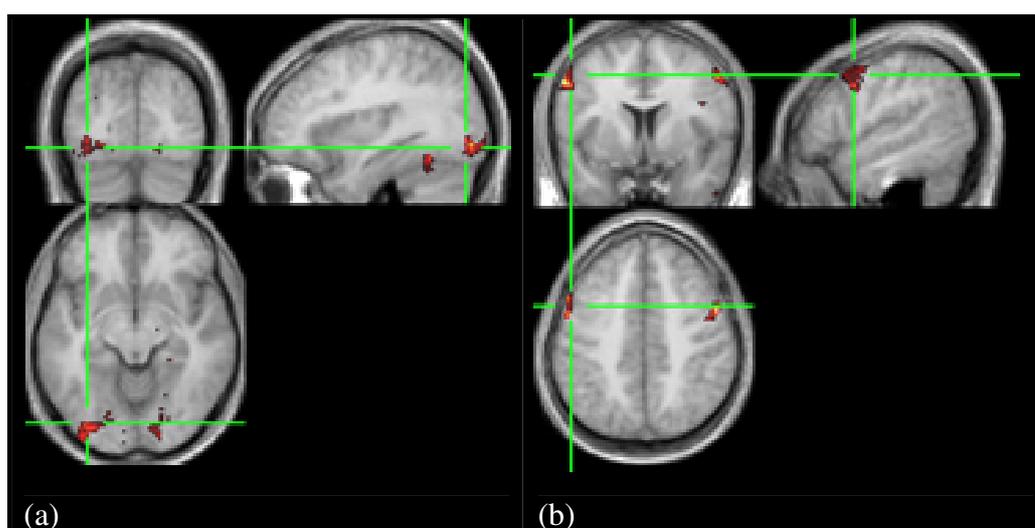


Figure 4.2. (a) Activation in the inferior occipital area is stronger on the left than on the right side. (b) Significant deviant-related activation in the premotor areas and SMA.

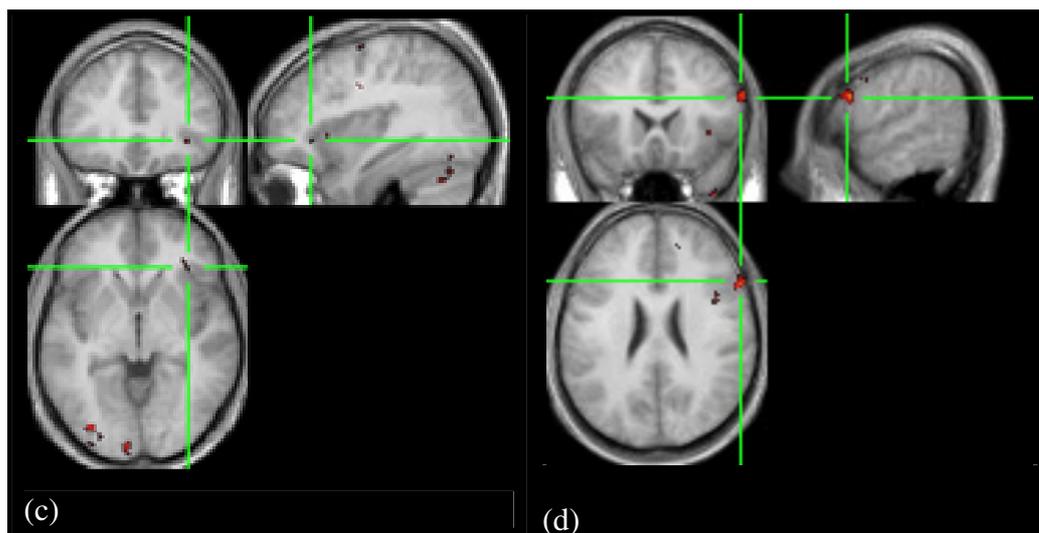


Figure 4.2. (c) Small but significant deviant-related activation is seen in the rIFG (BA47). (d) Right-sided inferior frontal gyrus on the lateral cortex (BA44).

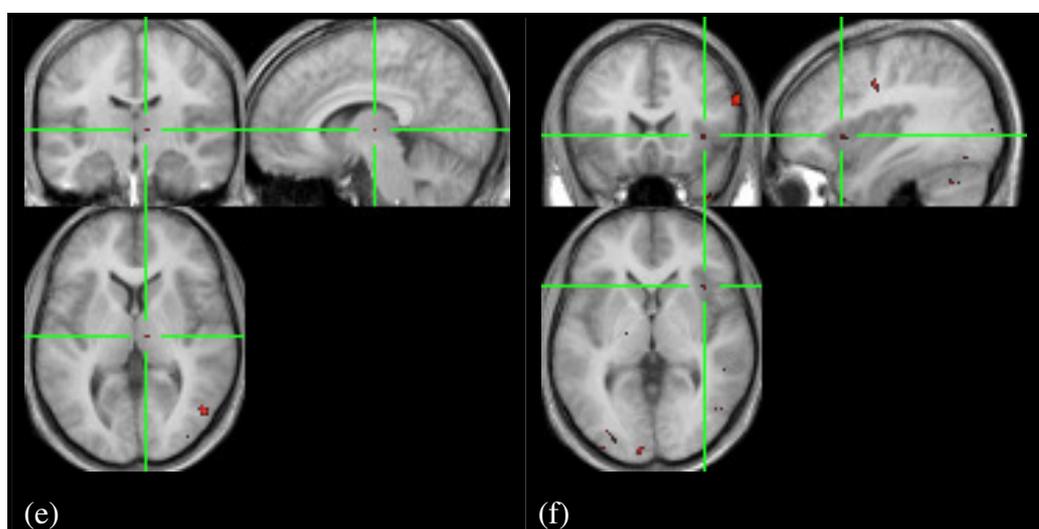


Figure 4.2. (e) Right-sided activation of the thalamus ($p=.01$, cluster=20). (f) Right-sided activation insula ($p=.01$, cluster=20).

In Table 4.1 the associated Talairach coordinates and the Brodmann area numbers for the voxel with the highest t-value in each cluster are listed.

Table 4.1. Brain regions showing significant activation or deactivation in response to deviancy. Listed are the associated Brodmann area numbers of the region, the Talairach coordinates for voxel with the highest t-value in cluster, clustersize, and t- value with the an uncorrected $p=.001$. Note that * denotes $p=.01$ and $k=20$).

Brain region	Brodmann area	Coordinates			Volume (mm ³)	t
		x	y	z		
Activation						
L Middle occipital gyrus	18/19	-29	-85	19	262	6.78
R Middle occipital gyrus	18/19	32	-92	8	121	4.95
R premotor cx and SMA	6	51	4	40	202	8.11
L premotor cx and SMA	6	-57	8	36	169	8.11
R-IFG-opperculus part	44	59	18	23	62	6.46
R-IFG-orbital part		34	31	-6	10	4.65
R-Thalamus		8	-16	4	24	4.64 *
R-Insula	15	37	19	-1	104	3.74 *
Deactivation						
ACC	12/32	8	36	-5	30	6.75
PCC	23/31	-4	-45	30	22	4.47

The deviance processing produced less activation than the processing of the standard in the cingular cortex. Fig. 4.3 shows the areas, which showed a relative reduction of the BOLD response. Larger deactivations displayed in blue were found in the posterior cingular cortex (PCC) and anterior cingular cortex (ACC).

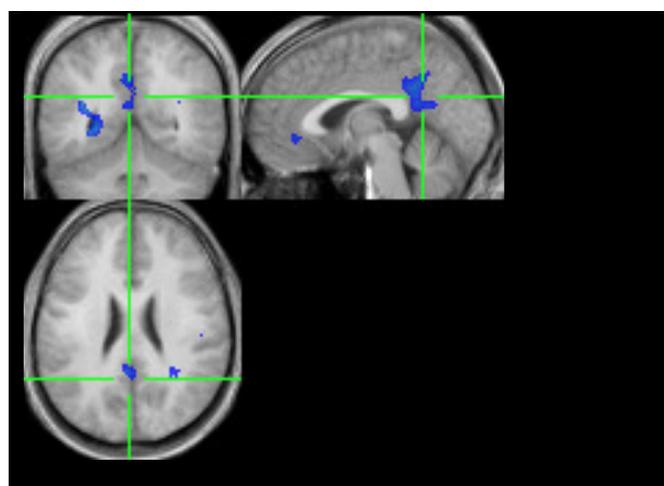


Figure 4.3. Large deactivations were found in the PCC and the ACC.

4.4 Discussion

The present experiment was performed in an attempt to explore which brain areas respond to the deviant stimulus in a visual mismatch detection task. It was expected to measure a reaction in occipital, parietal frontal and limbic areas. Together these areas could form a functional network related to the mismatch response.

On presentation of a deviant stimulus the middle occipital gyrus, premotor cortex and SMA, IFG, thalamus and insula showed an increase in BOLD signal, whereas the ACC and PCC showed a decrease in BOLD signal relative to the resting state. In response to the standard stimulus little or no activation was found in these (Näätänen, 1990) regions. Due to the high presentation rate of the standard, the change in signal intensity might not have been large enough to measure a BOLD signal since in between stimuli the region had little time to regulate back to a base level of activation.

Amongst the regions activated on presentation of a deviant were the left and right occipital gyrus showing a stronger activation on the left side. The fact that quite a strong activation was found in the occipital lobe showed that the processing in response to the deviant activated certain regions other than those activated by the standard. If there had been overlap between the regions activated by standard and deviant then most likely no BOLD signal would have been measured due to the small change in signal intensity. Hence, the activation found was not an effect of spatial frequency, but of deviancy. The gratings used as deviant were of high as well as of low spatial frequency. Therefore, it could be concluded that the activation found in the occipital regions after the presentation of a deviant are related to the primary modality-specific mismatch detection (Downar et al., 2000).

In the frontal lobe activation was found in the right inferior frontal gyrus. This activation fits in well with theories suggested by e.g., Posner (Posner & Petersen, 1990) and Burgess and Shallice (Burgess & Shallice, 1996) on the functional role of the anterior portion of the frontal lobe. Posner proposed the existence of an executive branch of the attentional system, which is responsible for focussing attention on selected aspects in the environment. Along these lines, Shallice and Burgess suggested that attention is regulated by a so-called supervisory system which can override automatic responses in favour of scheduling behaviour on the basis of plans and intentions (response inhibition). When viewing the mismatch detection task in this light it can be theorised that the attention was focused on the correct performance of the 2-CRT tasks in order to quickly detect the target stimuli and deliver an adequate response. When potentially distracting stimuli are suddenly presented this functional region might have been activated to avoid interference with performance. It could have played a role in the inhibition of automatic responses the

deviancy (e.g., orientation). Empirical evidence comes from GoNogo and stop-signal studies, where a speeded response is required to 'go' trials and to inhibit responses to 'nogo' or 'stop' trials. Response inhibition usually activated the rIFG (Chikazoe, Konishi, Asari, Jimura, & Miyashita, 2007; Menon, Adleman, White, Glover, & Reiss, 2001; Garavan, Ross, & Stein, 1999; Konishi, Nakajima, Uchida, Sekihara, & Miyashita, 1998). Additionally, the findings from a study by Aron and colleagues (Aron, Sahakian, & Robbins, 2003) on patients with right frontal lobe lesions indicated that rIFG damage was related to failures in inhibiting irrelevant sensory input (see also Chao & Knight, 1995; Deouell et al., 2005).

Also, bilateral activation of the SMA was seen on the activation maps. Usually activation in this region has been associated with the planning of motor responses associated with voluntary actions (Cunnington, Windischberger, Deecke, & Moser, 2002; Luppino & Rizzolatti, 2000). Downar et al. (2000) have suggested that this activity could be attributed to the planning of involuntary motor orienting responses to the changes in visual input, especially, since none of the stimuli used in their study required a motor response. However, in the present study it could not be completely excluded that part of the activation resulted from the planning of motor responses for the 2-CRT task.

The activity in the insula reached significance in the right hemisphere. Previously, insular activation was found in a change detection study (Downar et al., 2000), but also in studies involving active visual oddball paradigms (Ardekani et al., 2002; Linden et al., 1999; Fichtenholtz et al., 2004) thus supporting the notion of its role in the network for processing of visual stimuli.

It is well-known that the lateral geniculate nucleus (LGN) is part of the visual pathway. As a relay-station it transfers visual information from the retina directly to V1. Considering that most visual information follows this pathway it is unlikely that the thalamic activity found in the present study is related to this stimulation. The LGN would be activated by all stimuli presented and it is more likely that the overall level of activation did not change significantly during or following transitions. Therefore, it is hypothesised that the activity found in the right sided thalamus could be associated to higher cognitive processes related to mismatch detection (Ardekani et al., 2002; Clark, Fannon, Lai, Benson, & Bauer, 2000; Yoshiura et al., 1999).

The right TPJ is activated when stimuli are presented outside the attentional focus and is thought to play a role in detecting salient stimuli and in attention reorienting (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Pollmann et al., 2003; Downar et al., 2000). Additionally, lesion studies have shown that patients with lesions of the right TPJ have much more difficulty responding to irrelevant stimuli outside the attentional focus (Friedrich, Egly, Rafal, & Beck, 1998; Lepsien & Pollmann, 2002). In the present study, TPJ activation was seen in the right hemisphere, but none of the voxels in this region reached the set threshold. Therefore, it was not possible to confirm the findings from the earlier studies by Rinne et al., (2000) and Downar et al. (2000).

Task-induced deactivation has been demonstrated to occur consistently in specific brain regions. These regions include e.g., posterior cingulate cortex, dorsomedial prefrontal cortex, and rostral anterior cingulate gyrus (Mazoyer et al., 2001; McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003; McKiernan, D'Angelo, Kaufman, & Binder, 2006). However, the mechanisms underlying these deactivations are not completely understood. Deactivations could reflect passive shunting of blood to activating areas, but could also reflect active inhibition (Frankenstein et al., 2003). According to a model proposed by McKiernan et al. (2003) task-induced activations are related to a mechanism of reallocation of brain processing resources. In support of this model they introduced their observations of a correlation between task difficulty and the magnitude of task-induced activations in brain regions. These deactivations might stem from internally generated processes in a situation where attentional resources are required for performance of an effortful task. One possible explanation of the deactivations found in the present study could therefore be that these were the result of capacity limited processes in the brain. Especially, since they were found in the PCC and ACC, which previously have been associated with deactivations (Mazoyer et al., 2001; McKiernan et al., 2003; McKiernan et al., 2006). In this case capacity limited processes might have included working memory, for it is likely to be required for performance of the primary task as well as the mismatch task (Kimura et al., 2005).

In conclusion, it can be said that a series of regions were found showing a BOLD response upon the presentation of a deviant stimulus, which were also associated with previous auditory and visual studies. The method used in this experiment

allowed for the identification of several areas which together could form a functional network involved in the process of mismatch detection. However, it should by no means be thought that these are the only areas involved. It is important to realise that although no change in signal intensity was measured in other regions, those regions could still be part of the functional network. When no signal was detected in a certain area it could have resulted from the overall level of activation, which did not change significantly during the performance of the task. This could occur when a certain region is involved in the processing of the standard as well as the deviant or the 2-CRT task (Downar et al., 2000). Another example involves areas related to working memory. Both the performance on the 2-CRT task as well as the execution of the mismatch detection task were thought to rely on working memory (see also Linden et al., 2003). Therefore, it could be expected that some areas cannot be made visible due to the high demand on these areas. To avoid the visibility problem of areas involved in mismatch detection it will be necessary to carefully plan the demands of the primary task and the mismatch detection task in future research. Especially timing of events should be carefully controlled in further studies to avoid obscuring of activity due to functional overlap in certain regions that are involved in both tasks.

Chapter 5

The relationship between visual mismatch detection and measures of impulsivity

5.1 *Impulsivity or impulsiveness: a short statement on terminology*

Before starting the chapter a statement has to be made on the terms used to refer to impulsive behaviour in the literature. Some authors refer to it as impulsiveness and others as impulsivity. In the following chapters the term will be used according to the preference of the author of the theory or test described. However, as my personal preference goes out to the term impulsivity, this will be used in the more general parts on impulsive behaviour.

5.2 *The theoretical background of impulsivity*

Impulsivity is a broad personality concept which is not only associated with psychopathology, learning and social disorders, but it is also considered an aspect of everyday normal functioning. There are different approaches for the study of impulsive behaviour: the personality theoretical approach, the behavioural approach where impulsivity is seen as behavioural activation, and the cognitive approach (Gerbing, Ahadi, & Patton, 1987; Stanford, Ebner, Patton, & Williams, 1994).

The personality theories of impulsivity have some aspects in common. Concrete impulsive behaviour is usually described as uninhibited and with a lack of control, ranging from aggressive acting out to eating disorders. Impulsivity is mainly defined by the tendency to (re)act fast, but without thinking or considering the consequences of the action (Lennings & Burns, 1998).

In the framework of personality models impulsivity is thought to be a facet of the basic personality dimensions. The lack of behavioural control is seen as an outstanding characteristic of the individual. The influential personality theory of Eysenck comprises three dimensions: Extraversion/Introversion, Neuroticism, and Psychoticism. Impulsiveness is a subordinate of these dimensions. In the original concept, impulsiveness was a subfactor of Extraversion in the Eysenck Personality Inventory (EPI) (Eysenck & Eysenck, 1964). In this inventory four subtraits of impulsivity were distinguished: Impulsivity in the narrow sense (acting without thinking), risk-taking, non-planning and liveliness. The latter trait of impulsivity, liveliness, shows that impulsive behaviour is not only regarded as purely dysfunctional, but that it can also have its functional sides. Later, when the Eysenck

Personality Questionnaire was introduced, the concept of impulsiveness was no longer put under the Extraversion dimension, but was included in the Psychoticism dimension. In addition to the changed position of impulsiveness, the Eysencks developed an Impulsiveness scale as part of an Impulsiveness-Venturesomeness-Empathy Scale (IVE) (Eysenck & Eysenck, 1978). The final version of the Impulsiveness Questionnaire was I7 (Eysenck, Pearson, Easting, & Allsopp, 1985) and will be discussed in more detail further on.

Barratt and Patton (1983) viewed upon impulsivity as behavioural activation. The first version of the Barratt Impulsiveness Scale (BIS, Rorden et al., 2006) was based on a unidimensional model of impulsiveness which included it as a part of a larger group of personality predispositions such as extraversion, sensation seeking, and a lack of inhibitory behavioural control. However, further research led Barratt and Patton to classify impulsiveness into three main factors: motor (acting without thinking), attentional/cognitive (quick cognitive decision making), and non-planning (present-oriented or lack of futuring). The motor factor and the attentional/cognitive factor are seen as biologically anchored aspects of information processing. Related psychophysiological theories assume that the increase in cerebral activation is badly regulated and can lead to sensoric overstimulation (Herpertz & Sass, 1997). On the other hand, the latter factor, the non-planning impulsivity, is perceived as an expression of lifestyle and more based on social learning than on physiology.

Psychological impulsivity concepts are not only limited to behavioural aspects of personality, but also include aspects on a more functional level through cognitive characteristics. The two main cognitive characteristics are “high speed” and “a lack of control” (Herpertz, 2001). The construct of cognitive impulsivity is not a recent one. It originates in the works of Kagan, who defined two opposing cognitive styles: reflection or impulsivity (Yando & Kagan, 1970). His definition of impulsivity was the fast, but imprecise use of information in perception and problem solving tasks. Such a cognitive style leads to a shorter period of time between the impulse to act and the action itself, which in turn only allows for a small window of opportunity for control mechanisms to operate in. His definition was based on research in children. It was found that impulsive children performed much faster on problem solving tasks and visual discrimination tasks, however, without carefully considering their answers.

Kagan concluded from his research that the high speed in mental processing was the core cognitive characteristic of the impulsive personality.

Thus impulsivity is not regarded as a purely dysfunctional and negative characteristic. In certain situations it can be seen as functional and can contribute to a positive outcome. A good example is of an impulsive subject who has adopted rapid information processing strategies. On certain cognitive tasks this subject manages to complete so many items in the time available that they are able to produce more correct items than other subjects in spite of a higher error rate (Dickman, 1990). This behaviour only then becomes dysfunctional, when further increases in speed increase the error rates so much that the greater number of items no longer compensates for the high error rate. Similar results were shown by Barratt (1994) in a simple decision making target-response task. The subjects with the more impulsive personalities did better on this simple task. However, when the difficulty of the task was increased by increasing the information load and prolonging the delay till response, these impulsive subjects were no longer performing better than the non-impulsive subjects. This was explained by the changed demands of the task. In the more difficult version it was necessary to be able to switch flexibly between responding and delaying the response till the response signal. It was thought that impulsive personalities would have more difficulties with the flexible switching between behaviours (see also Barratt, 1985).

In summary, the literature showed that a core description of impulsivity includes a range of behaviours like acting without thinking, making quick cognitive decisions, making erroneous responses, and the fast, but imprecise use of information in perception and problem solving tasks.

5.3 *Techniques to measure impulsivity*

5.3.1 *Questionnaires*

In psychology it is quite usual to utilise psychometric self-report trait measures to acquire personality characteristics. The advantage of this method lies in it being a standard procedure, which makes comparisons amongst different studies possible. Another advantage is that most questionnaires are developed based on a theory, which makes it possible to interpret the score of the questionnaire in a theoretical

framework. Disadvantages of utilising a questionnaire is that they usually comprise multiple impulsivity aspects and the trait impulsivity is so defined in a very broad way. This could become a problem when only one aspects of impulsivity is looked at. Another disadvantage concerns whether the impulsivity measured by a questionnaire is comparable to the impulsivity measured at a behavioural level. A person, who describes himself as impulsive, does not necessarily show impulsive behaviour on a test.

In the following part two questionnaires measuring impulsivity and the development thereof will be discussed: the Eysenck Impulsivity Questionnaire (Eysenck, Daum, Schugens, & Diehl, 1990) and the Barratt Impulsiveness Scale (Rorden et al., 2006).

The I7 comprises three subscales, Impulsiveness, Venturesomeness, and Empathy, with Empathy as a distractor scale. The subscale Impulsiveness includes several different aspects of impulsivity, for example the tendency to speak and act without thinking, not taking negative consequences into consideration, and too fast, erroneous performance. In the current work a standardised German version has been used (Eysenck et al., 1990). This version contains 54 items, 17 items for impulsiveness, 16 items for venturesomeness and 14 items for empathy. Initially, the empathy items were thought of as buffer items. However, since there was a good cohesion with the other items, this factor was refined in subsequent studies and retained.

The BIS is probably the most well-known and most utilised instrument to measure impulsivity. The original was drawn up in 1959 and has since been revised extensively (Barratt & Patton, 1983). In 1995, Patton and colleagues did a study with the purpose to revise the BIS-10 by identifying the factor structure of the items, which resulted in the BIS-11 (Patton, Stanford, & Barratt, 1995). Three second-order factors were identified: motor impulsiveness, non-planning impulsiveness and attentional/cognitive impulsiveness. The first two factors were consistent with previous studies (Barratt, 1985). The results for the third factor of attentional/cognitive impulsiveness were not consistent with Barratt's theoretical position which postulates a cognitive impulsiveness factor (Barratt, 1985). In the study here discussed, cognitive items loaded on all of the factors, which suggested that cognitive processes underlie impulsiveness in general. Two possible explanations were brought forward to explain this. The first explanation was that a

cognitive impulsiveness does not exist. The second one was that the relationship of the BIS with cognitive processes may be because the latter are characteristic of impulsiveness per se. They did not interpret this result any further and summarised their findings saying the “pure” cognitive impulsiveness component was evident. Another finding of their study was that motor impulsiveness and non-planning impulsiveness were similar to the Eysencks’ impulsiveness subtraits of impulsiveness narrow and non-planning, respectively (Patton et al., 1995). However, the attentional/cognitive impulsiveness factor was not similar to any of the Eysenck subtraits.

5.3.2 Behavioural measures

In addition to questionnaires, behavioural tasks can be used to measure impulsivity. As mentioned above there is an association between impulsivity and a lack of inhibition.

Three types of inhibitive functions can be differentiated according to the model of Harnishfeger (1995). One inhibitive function is controlling interference, which is the inhibition of a competing, internal or external, stimulus or set of answers, which evokes competing motor responses. A second type is cognitive inhibition, which means the active suppression or exclusion of task-irrelevant information from the working memory. And the third type is behavioural inhibition, which is the inhibition of prepotent or automatic actions. Several different paradigms can be used to test these types of inhibitive behaviours. Examples of tasks used for this purpose are the Stroop-test (MacLeod, 1991), the Continuous Performance Test (CPT), the Stop Signal Task (Logan, 1994) and the GoNogo task (Barratt, Stanford, Kent, & Alan, 1997).

In the present work the GoNogo (also called Recognition) reaction time task was used as a measure of impulsivity. This task measures the ability to inhibit a well-learned response and tends to have good test-retest reliability (Kindlon, Mezzacappa, & Earls, 1995). The paradigm consists of two classes of stimuli: “Go” stimuli which require a response such as a button press and “NoGo” stimuli which require the withholding of this well-learned response (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005). The ability of the participant to withhold a response during the NoGo condition is an indication of the participant’s inhibitory control. The errors

that can be made during this task are similar to the ones in the CPT, omission and commission errors. Especially commission errors can help infer about possible attentional deficit problems or impulsivity (Horn, Dolan, Elliott, Deakin, & Woodruff, 2003).

5.4 *Impulsivity and information processing*

As was described at the beginning of the chapter, several behavioural aspects like the tendency to respond too fast and the error-prone performance are ascribed to the personality characteristic impulsivity. Much research into the differences between high- and low-impulsive personalities on a behavioural level has been done and the findings have been interpreted as being the result of deviant information processing. In the next part some of the research aiming to find indications of possible information processing deficits in impulsive personalities will be described.

The Augmenting/Reducing paradigm is used to show the changes in cortical arousal to stimuli of different intensity. Augmenting refers to the amplification of the stimulus related cortical arousal, whereas reducing refers to the reduction of cortical arousal. Augmenting is associated with an impulse-seeking, impulsive and uninhibited behavioural style. The behavioural measures used for these studies were mainly event related potentials (e.g., Barratt, Pritchard, Faulk, & Brandt, 1987; Zuckerman, 1991). The results showed that high impulsive persons have augmenting behaviour which is reflected in the increasing amplitudes of the ERP components in response to stimuli that increase in intensity.

Above, research has been described which aimed to show the differences in information perception in high and low impulsive persons. In the next paragraphs research into central or controlled information processing (e.g., reflection, problem solving, inhibition or the use of processing strategies) will be discussed.

A much used paradigm is the previously described GoNogo task. This paradigm is optimised to produce response inhibition, commission errors and the opportunity to correct subsequent behaviour. It was shown that high impulsive persons make more commission errors under motivational conditions where their responses are followed by a reward or punishment. The behavioural deficit was thought to be inhibition or response perseverance (Herpertz et al., 1997). Horn and colleagues (2003) used a

simple GoNogo with letters for stimuli in an fMRI study. They hypothesised the psychometric impulsivity scores to correlate positively with error-rate. In their study no correlation was found between the two. However, they did find that more impulsive individuals had different activation patterns of the studied brain regions than less impulsive individuals and tentatively interpreted that impulsive subjects recruited more neurons from these regions than less impulsive subjects to achieve the same degree of behavioural inhibition. This may be due to post-stimulus processing: more impulsive subjects may preferentially update strategy, while less impulsive subjects may not. Garavan et al. (2002) did report an association between absentmindedness (which correlates with BIS impulsivity) and response inhibition during the GoNogo task. Another finding for GoNogo task performance in high impulsive subjects was acceleration instead of a deceleration in response time on the trials after an error (Patterson, Kosson, & Newman, 1987). This may be interpreted either as a lack of reflection of one's own behaviour or as a deviant adjustment of the strategy used (Speed-Accuracy Trade-off).

Results on the interference Stroop task showed an increased reduction in response speed (Barratt et al., 1983) and more errors for the more impulsive subjects (White et al., 1994). It showed their susceptibility to interference and the difficulties experienced in conflict situations. On the other hand Dickman (Dickman, 1985) was not able to show a correlation between impulsivity and error-rate. According to the attentional-fixation theory of Dickman (Dickman, 2000), the difference between high and low impulsive persons lies in the degree to which attention tends to remain fixed on the current source of input. High impulsive persons shift their attention relatively easily from its current fixation, while the attention of persons with low impulsiveness is difficult to shift. This impulsive behaviour results in fast but erroneous responses on tasks like the GoNogo and the CPT. However, these are all tasks actively participated in and under intentional or voluntary control.

5.5 *Impulsivity and change detection*

Only in part of the previous investigations a relationship was established between the trait impulsivity and impulsive behaviour (Barratt et al., 1983; Garavan, Ross, Murphy, Roche, & Stein, 2002; Patterson et al., 1987; White et al., 1994). The results seem to point towards possible deviances in information processing in impulsive

subjects, however, an exact stage in information processing could not be pinpointed. It seems likely that there is more than one particular deviance in information processing, which makes it hard to get consistent results. Another reason for not finding consistent results may be due to the definition of impulsivity. It has a very broad definition and may comprise different forms of impulsivity.

In previous investigations on impulsivity and to which stage of information processing this may be related behavioural tasks were used which needed the active participation of the subjects (e.g., GoNogo task). One aspect of information processing which has hardly been regarded in relation to impulsivity is the non-intentional processing of incoming stimuli from the environment. The ability to adequately process task-irrelevant environmental information and the ability to notice unexpected events enable a flexible interaction with our everyday environment. This is exactly the stage where impulsivity has been studied in only one investigation, so far (Franken et al., 2005). Franken and colleagues set up a study to investigate the role of bottom-up processes in impulsivity. They debated that most studies stress the point that impulsivity relates to poor response inhibition supported by evidence from tasks like e.g. the GoNogo task or the stop-signal task. However, their study implies that impulsivity is also linked to behaviour which does not need the execution of a response (non-motor cognitive processes). Their results showed that the cortical responding (Horvath et al., 2008) towards external auditory stimuli, which occurs within 200ms after stimulation and is beyond voluntary and intentional control, is positively related to self-reported impulsivity as measured by the Dickman questionnaire DII.

5.6 The present study

Processing of information is usually modelled as existing of several stages like preprocessing, feature extraction, and response choice. Impulsivity could influence one or more of the stages of information processing (Barratt et al., 1983; Sanders, 1983; White et al., 1994; Zimmer, 2001). In the present study the relationship of impulsivity to amplitude measures of deviance processing in the visual mismatch detection task is investigated. For this purpose the impulsiveness subscale of the I7, the factors of the BIS and behavioural measures of the GoNogo task will be related to performance on the mismatch detection task. Based on the study by Horvath et al.

(2008) who suggested that smaller amplitude measures of the MMN are related to the number of detected deviants it is hypothesised that a high impulsivity score is related to lower amplitude measures of the vMMN since an impulsive cognitive style is defined by fast but not necessarily more precise processing. It seems likely that this type of processing could prevent the detection of small unexpected changes in the visual environment. It remains to be explored which impulsivity measure shows the strongest association with mismatch detection.

5.7 Method

5.7.1 Participants

Participants had all been part of the EEG and fMRI study described in Ch. 3 and 4. The sample consisted of 13 males aged between 20 and 36 years (mean age = 26.6, sd = 4.9). The questionnaires were answered on breaks in the EEG and fMRI part of the study. Prior to testing, written informed consent was obtained from all participants.

5.7.2 Questionnaires

Trait impulsivity was assessed using the Barrat's Impulsiveness Scale and the impulsiveness subscale of the I7. Both were used as they differ in their conceptual basis (Parker and Bagby, 1997).

Barratt Impulsiveness Scale, 11th Revision

The BIS-11 (Konradt, 1999; Patton et al., 1995) is a self-report questionnaire administered as a paper and pencil test with 30 statements written in the first person (Appendix B). The test comprised 3 subscales: attentional or cognitive impulsiveness (items 5, 6, 9, 11, 20, 24, 26 and 28), motor impulsiveness (items 2, 3, 4, 16, 17, 19, 21, 22, 23, 25 and 30) and non-planning impulsiveness (items 1, 7, 8, 10, 12, 13, 14, 15, 18, 27 and 29). The items were answered on a 4-point scale with the options: *never/seldom, sometimes, often or almost always/always*. For each question 1 to 4 points could be given. Before the score to the subscales could be calculated 10 negative items needed to be rescaled in the opposite order (items 1, 7, 8, 9, 10, 12, 13, 15, 20 and 29).

Impulsiveness Questionnaire I7

The German version of the Impulsiveness Questionnaire (I7, Eysenck et al., 1990) was administered comprising three subscales: impulsiveness, venturesomeness and empathy (Appendix C). Items were answered with *yes* or *no*. To calculate the score only the items answered with *yes* received one point. For the present study only the subscale impulsiveness was used.

5.7.3 GoNogo task

A simple GoNogo paradigm was developed to probe response inhibition without loading working memory too much. The stimuli consisted of all letters of the alphabet. The Nogo-stimulus was the letter 'V' and the Go-stimuli were all other available letters (Horn et al., 2003). A trial started with a centrally presented fixation cross which was replaced by letter. Participants were required to focus on the fixation cross and press a button as quickly as possible in response to the Go-stimuli and to withhold a response to the Nogo-stimulus.

The experiment was controlled by Presentation software (Neurobehavioral Systems, Albany, CA, USA) using a monitor with 60Hz refresh rate. The letters were presented as black capital letters in font-size 85 and font-type Times New Roman on a grey background (colourcode:127,127,127). The viewing distance was about 100cm. The stimuli were randomly presented with a duration of 200 ms and the time in between stimuli varied from 600 to 1400 ms. Each of 4 blocks consisted of 176 stimuli (ratio Go:Nogo was 10:1).

ERP components

To evaluate the deviant-related components difference waves were calculated by subtracting the standard ERP from the deviant ERP which resulted in a measure of the amount of displacement of the ERP on presentation of the deviant. On basis of its known negative polarity and typical latency range a MMN-like deflection was identified from the grand averaged waveforms at the posterior channels (time interval 80-144 ms, T1). Accordingly, area measures were computed at the three midline channels (Fz, Cz, and Pz) and the posterior channel Oz.

5.8 Results

Table 5.1 shows the mean scores, standard deviations and range for the I7 impulsiveness scale, all subscales of the BIS and the total BIS score. A high score on

Table 5.1. The mean scores (SD) for the I7 impulsiveness subscale and the subscales and total score of the BIS. Additionally the range and the maximal possible score are given.

	Mean score (SD)	Range (max)
I7 Impulsiveness subscale	7.5 (4.4)	1 – 15 (17)
BIS attentional/cognitive factor	17.8 (3.3)	13 – 23 (32)
BIS motor factor	23.0 (3.9)	18 – 29 (44)
BIS non-planning factor	15.5 (3.7)	10 – 22 (44)
BIS total score	56.6 (9.4)	44 – 71 (120)

the questionnaire implies a high measure of impulsivity.

In Table 5.2 the Pearson correlations are given between the different impulsiveness measures. Only the correlations of the I7 with the BIS motor factor and with the BIS total score became significant. For the BIS attentional/cognitive factor and the non-planning factor a trend was seen.

Table 5.2. Pearson correlations and significances between the I7 impulsiveness scale and the BIS subscales and total score.

	BIS attentional/cognitive factor	BIS motor factor	BIS non-planning factor	BIS Total score
I7 Impulsiveness subscale	-	.70 <i>p</i> < .01	-	.58 <i>p</i> < .05

The RTs for the Go-stimuli and for the commissions, as well as, the percentage of commissions are displayed in Table 5.3. The percentage of commissions is the number of false responses on the total number of Nogo-trials. For the RTs only times up to 500 ms were included in the calculation of the mean RT.

Table 5.3. The behavioural results of the performance on the Go-Nogo task with RTs for correct answers to Go-stimuli, for commissions and the percentage of commissions.

RT (SD) for correct answers to Go-stimuli	346.79 ms (47.01)
RT (SD) for commissions	308.35 ms (37.76)
Percentage of commission	36.1 %

In Table 5.4 Spearman correlations are given for all impulsivity measures of the two questionnaires with the behavioural measures of the GoNogo task. Negative correlations were found for I7 impulsiveness with the reaction times on the Go/Nogo task. A positive correlation was found with the percentage of commissions: a higher impulsivity score is related to a higher percentage of commissions.

Table 5.4. Spearman correlations between the impulsivity measures from the questionnaires and the behavioural measures of the GoNogo task.

	% commissions	RT-Go	RT-commissions
I7 Imp	.52*	-.57*	-.57**
BIS attentional/cognitive factor	-	-	-
BIS motor factor	-	-	-.50*
BIS non-planning factor	-	-	-
BIS total	-	-	-.52*

Note: * $p < .05$, ** $p < .01$

Table 5.5 shows the Spearman correlations for the impulsivity measures from both questionnaires and the with the amplitude measure from the mismatch detection task. The amplitude measure comes from the time interval from the grand mean difference wave as described above. The first time interval, ranging from 80 to 144 ms after presentation of the stimulus, is related to the visual mismatch negativity. The second time interval ranges from 144 to 180 ms and represents a large positive deflection of the ERP which occurred in response to the deviant.

Table 5.5. Spearman correlations between the impulsivity measures from both questionnaires, and the behavioural measures of the GoNogo task with the amplitude measures of the mismatch detection task (N=10).

	T1-Fz	T1-Cz	T1-Pz	T1-Oz
I7 Impulsiveness	-	-	-	-.76 **
BIS attentional/cognitive factor	-.53 *	-.54 *	-	-
BIS motor factor	-	-	-	-.62 *
BIS non-planning factor	-	-	-	-
BIS total	-	-	-	-
% commissions	-	-	-	.
RT-Go	-	-	-	.58 *
RT-commissions	-	-	-	.67 *

Note: ** $p < .01$, * $p < .05$

Negative correlations were found between the impulsivity measures and the channels Fz, Cz and Oz, which indicate that a high impulsivity score is related with a low amplitude measure. Positive correlations were found with RT measures of the GoNogo task which implied that a fast executed response is related to a small negative shift of the deviant related ERP. In Figure 5.1 an overview of the correlations between the impulsivity measures and the amplitude measure is given.

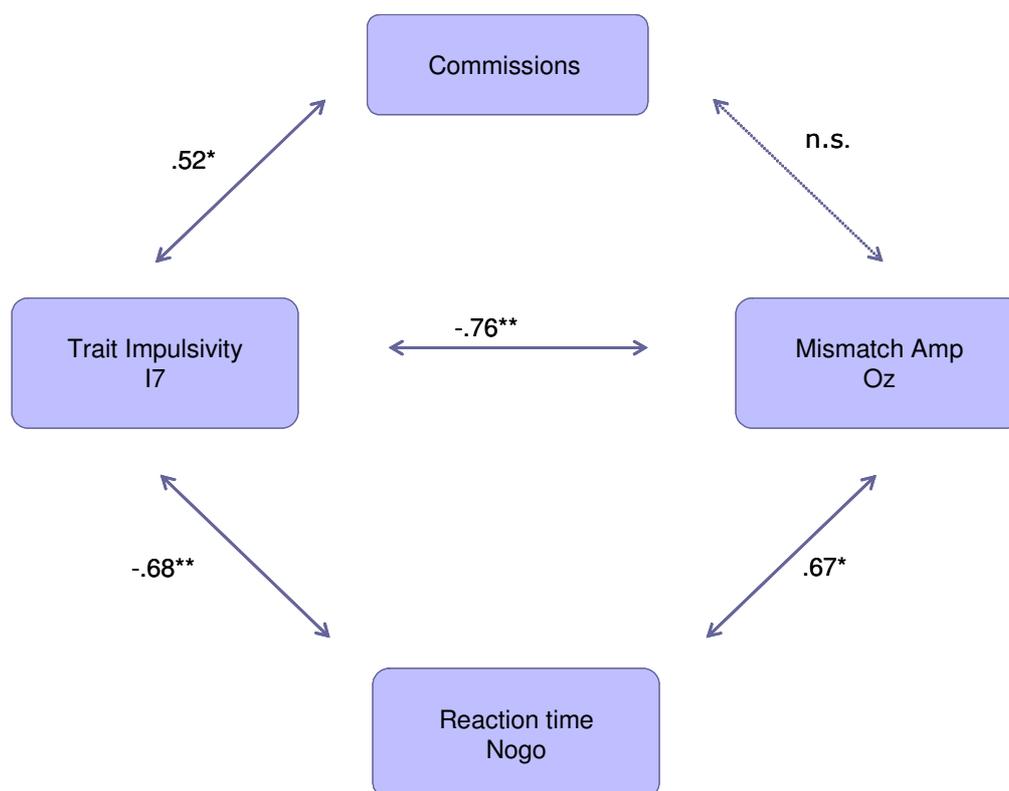


Figure 5.1. Shown is an overview of the Spearman correlations between the different impulsivity measures and the amplitude measure of the mismatch reaction. The black arrows indicate the direct correlations between the variables and the grey arrows indicate the correlation from combined measures with mismatch amplitude. The non-significant correlation is displayed with a dotted line.

5.9 Discussion

The main aim was to investigate the relationship of impulsivity and the non-intentional processing of task-irrelevant visual information. To measure trait impulsivity the German versions of the I7 and the BIS were used. The GoNogo task was used to measure the behavioural impulsivity. The measures for the task-irrelevant processing, vMMN, was derived from the visual change detection task.

The most important finding in the present study was that a high score on the I7 impulsiveness subscale was associated with low amplitude measures of the vMMN at channel Oz. According to Horvath et al. (Horvath et al., 2008) low amplitude measures indicate a bad detection of the deviant in the mismatch detection task. This result would first of all support the notion that impulsivity could already play a role at

a very early stage of information processing and could play a role in how precise the information is processed.

However, this negative association between the measures opposed the findings of the only other associated study by Franken and colleagues (2005), who showed a positive relationship between the amplitude of the auditory MMN and the self-reported impulsivity scores of the DII (Dickman, 1990). The difference between the two studies primarily lies in the modality investigated: visual vs. auditory. At this point in time the exact nature of the processes underlying visual change detection are still unknown (Czigler, Personal communication, 2008.06.09). These processes could differ from those taking place in the auditory change detection process and could so lead to the different relationship to impulsivity.

Another interesting finding of the present study was that both the vMMN amplitude and commission error rate were related to reaction time, but not to each other. Fast responses were related to low amplitude measures of the vMMN and a high rate of commission errors. As response speed was also strongly related to impulsivity the underlying factor seems to be fast and imprecise information processing, causing a bad detection and higher error rate. However, vMMN amplitude and error rate are not associated and different processes seem to take place. A bad detection of the Nogo stimulus is not the reason for the commission errors (Elton, Spaan, & Ridderinkhof, 2004). It is thought that commission errors have to do with the time-window available for inhibitive functions to exercise their influence at the stage of response choice in information processing (Cooper, Sagar, Tidswell, & Jordan, 1994). When not enough time is available the prepotent Go-response cannot be inhibited and will erroneously be used in a Nogo situation.

The cognitive-energetic model by Sanders (1983) seems to offer a more accurate interpretation of the results. Sanders proposed that information processing can be modelled encompassing different stages of processing whilst taking into account the status of the organism and with RT as a measurable outcome of the process (see also Ch.1). According to Sanders' model, the early processing of the deviant occurs at the preprocessing stage of information processing on the base level. The occurrence of commission errors is related to the later stage of response choice also at the base level (Mostofsky & Simmonds, 2008). One tentative conclusion which could be drawn from this is that the impulsivity can have an

influence at different stages of information processing, although not necessarily at the same time.

When regarding trait impulsivity only the I7 impulsiveness subscale correlated well with all three measures of the GoNogo task. The results for the BIS were not as clear. The BIS motor subscale and the total score were associated with the RT for the commissions, but not with the RT on correct responses or the percentage of commission errors. These results for the BIS were supported by other investigations where no correlation between the BIS impulsivity scores and error-rate was found (Barratt et al., 1983; Horn et al., 2003). Additionally, Dickman was not able to find an association between impulsivity measured with Dickman's Impulsivity Inventory and error rate (Dickman, 1985).

Nevertheless, the relationship between the I7 impulsiveness subscale with the percentage of commission errors is plausible, since the conceptual basis of the utilised questionnaires are different (Parker, Michael Bagby, & Webster, 1993). (Dolan, Anderson, & Deakin, 2001) presumed that the Impulsiveness scale by Eysenck and Eysenck is more closely related to neurobiologically mediated aspects of impulsivity than the BIS and therefore will show a better relationship with psychometrical measures. Additionally, it is known that the impulsivity measured by a questionnaire is not always comparable to the impulsivity measured at a behavioural level since a person who describes himself as impulsive, does not necessarily show impulsive behaviour on a test.

One note of caution has to be given on the stimulus material when interpreting the results of this study. The manner in which the information was offered might be a factor to consider, too. For the visual mismatch task the information (standard and deviant stimulus) was offered very briefly at a non-attended location and was irrelevant for the performance on the primary task. The stimuli of the GoNogo task, however, were presented longer and had acute relevance for correct performance on the task.

In summary it can be said that the cognitive style characterised by impulsivity covers a range of behaviours like acting without thinking, making quick cognitive decisions, erroneous responses, and not paying attention to details. In short, an impulsive cognitive style can be described by fast, but not necessarily more precise processing.

In the present study a relationship could be established between the detection of changes in a visual detection task and trait impulsivity measured by the I7 impulsiveness scale. However, no relationship was found between the detection of changes and another type of impulsive behaviour: commission errors in a GoNogo task. It seems that trait impulsivity can separately be related to different stages of information processing.

Chapter 6

Summary and conclusions

Within this thesis three studies have been presented dealing with the detection of visual change. The first study was carried out in order to develop a paradigm suitable to investigate the phenomenon of visual change detection. Once this ERP component, the visual mismatch negativity, had been established the same paradigm was implemented in an fMRI study. This second study was carried out in order to investigate which brain regions might part of a functional network for the detection of sudden changes in the visual environment. The third study was aimed at investigating the relationship between the ability to detect unexpected changes in the visual environment and impulsivity.

An ERP analysis of visual mismatch detection

The first study is based on a theoretical model explaining the reaction on sudden, and unexpected changes in the continuous information stream from the sensory environment designed by Näätänen and Alho (1995). A neural monitoring process is thought to continuously compare the neural representation of the current sensory input with the representation of the currently maintained standard. The currently maintained standard is based on previous repetitive input from the surroundings. Only when a discrepancy is found between the new neural trace and the maintained standard will the comparison process result in an electrophysiological mismatch reaction, the MMN. In previous investigations of the auditory modality (Näätänen, 1992) two components in the electrophysiological recordings, which are related to the deviance detection have been identified: an early sensory specific component and a later central component.

It seems unlikely that the brain, being very efficiently organised, has such a system in place for only one type of sensory input, which is why within this study a paradigm suitable to establish a comparable reaction in the visual modality has been designed. Based on the auditory model the assumption was made that a visual MMN can only be elicited by visual stimuli violating a detected regularity in the visual information stream (Czigler et al., 2002, Astikainen et al., 2004). The task designed to elicit a visual mismatch reaction was a hidden task presented to the naive participant whilst performing an attention demanding 2-CRT task.

Consistent with the model and some previous studies (Kimura et al., 2006; Pazo-Alvarez et al., 2003) it was found that a response could be established to a change or

deviance in a repetitive series of standard visual stimuli. The largest response to a deviant was a negative shift of the ERP at the occipital region. The negative shift was seen from the downward slope of the P1 to the downward slope of the P2 between 100 and 140 ms after the appearance of a deviant. This negative shift is termed the vMMN, the visual counterpart of the auditory MMN.

At the central midline evidence was found for a second component in the visual change detection process. In the time interval where at the occipital channels the negative deflection was found, a positive response to the deviant and standard gratings could be seen. In the time intervals from 100 to 180 ms the deviant elicited a larger response than the standard. This might be taken as an indication that also at a higher processing level the system is able to differentiate between a deviant and a standard stimulus (Czigler et al., 2007, Kimura et al., 2006).

One of the criteria the mismatch response has to meet is the independence of attention. To investigate this, the hidden mismatch detection task was presented in two conditions. The primary task which was actively performed to bind the attention was presented with two levels of difficulty. At Oz the vMMN was larger in the easy condition when compared to the difficult condition. This was specifically due to a different reaction to the deviant in the two conditions, since the reaction to the standard did not differ. At the frontocentral sites a general effect was seen. The responses to standard and deviant stimuli were larger in the easy condition when compared to the difficult condition. It may be assumed that level of distraction caused by the difficulty of the primary task has an influence on an underlying system automatically processing irrelevant visual information, but it does not abolish the processing of irrelevant information, nor the occurrence of the visual mismatch response.

An additional conclusion which could be drawn in this study concerned the distinct behavioural distraction effects of the changes in the irrelevant visual background on the performance of the 2-CRT. When a deviant grating appeared in a series of standards the RTs on the 2-CRT task were slowed. The distraction, however, did not induce an increase in error percentage on the 2-CRT task performance. Considering that a slower RT is found on the processing of a deviant grating and that task load has an effect on the response to stimulus change at an unattended location, it is assumed that both processes rely on the same underlying neural process of working

memory (Berti and Schröger, 2003; Rinne et al, 2000, 2006; Maekawa et al., 2005; Czigler et al., 2004; Kimura et al., 2005).

Limitations of the study

Several criteria have to be fulfilled before a component can be called an (v)MMN. These criteria are independence of attention, endogeneity, sensory discrimination and sensory memory and associations of attention orienting should be observed. The presented study comprised only one paradigm with which it was possible to make inferences on independence of attention, endogeneity and involuntary attention switching, but not on the criteria sensory discrimination or sensory memory.

The criterion of sensory discrimination can be tested by increasingly varying the frequency of the deviant gratings relative to the standard. Even though in the present study two frequency variations were used, the fulfilment of the criterion of sensory discrimination is assumed based on the results Maekawa and colleagues (2005).

The vMMN is thought to be related to sensory memory where supposedly the neural traces of the standard are kept and updated. To be able to test the sensory memory the paradigm needs to be varied with changes in probabilities of the standard stimulus or the length of the inter-stimulus- interval. However, in the present study the probability of the presentation of the standard was the same for all blocks. And although in the present study the inter-stimulus-interval between standards varied between 350 and 450 ms it is not entirely clear whether for visual stimuli these variations are enough to make assumptions about sensory memory. More in-depth research is needed to confirm the criterion of sensory memory.

An fMRI analysis of visual mismatch detection

In the second study the aim was to determine which brain regions might be involved in the processing of the standard and deviant stimuli from the visual mismatch detection paradigm. Based on the model on change detection from Näätänen (1991) activations were not only expected to be found in the sensory specific visual regions, but also in non-specific areas which could be related to the frontocentral component found in the ERP study. The latter is also based on a study by Downar and colleagues (2004) who were able to show activation in a number of regions in a design including changes in mixed auditory, visual and somatosensory stimulus

series. Some of these regions were activated independent of the type of stimuli used. Based on this study and other purely auditory studies the TPJ, inferior and superior frontal cortex, cingulum, SMA and insula are considered to be candidate regions.

On presentation of a deviant stimulus the left and right side of the middle occipital gyrus, the premotor cortex, SMA, IFG, thalamus, and insula showed an incline in BOLD signal, whereas the ACC and PCC showed a decline in BOLD signal. The activation of these regions seems to indicate that the processing in response to the deviant activates certain regions other than those activated by the standard. If there had been an overlap between the regions activated by standard and deviant then most likely no BOLD signal would have been measured due to the high presentation rate of the stimuli.

The method used in this experiment allowed for the identification of several areas which together could form a functional network involved in the process of mismatch detection. One can speculate upon the function of some regions in this network. The activation in the rIFG might be related to inhibition of e.g., the orienting response as to avoid interference of deviance detection with the performance on the 2-CRT task, which was the relevant task for the participant. Findings of GoNogo studies (e.g., Chikazoe et al., 2007; Garavan et al., 1999) and lesion studies investigating right frontal lobe damage (Aron et al., 2003) seem to confirm this. Usually, this region is activated during response inhibition of the GoNogo task, and lesions of this area are related to failures in inhibiting irrelevant sensory input (Deouell et al. 2005). The bilateral SMA activation is thought to be related to the planning of involuntary motor orienting responses to the deviances in the visual input (Downar et al., 2000). As it is the right TJP which is usually activated when stimuli are presented outside the focus of attention, it has been suggested that this region plays a role in detecting salient stimuli and the reorienting of attention (e.g., Corbetta et al., 2000).

Besides the described activations, large deactivations were found in the PCC and the ACC. The mechanism underlying deactivations is not completely understood as yet. Deactivations could reflect the passive shunting of blood to activating areas, or it could reflect active (functional) inhibition of these regions. McKierman et al. (2003) proposed that task-induced activations are related to a mechanism reallocating the brain's processing resources when these are limited. For change detection the

deactivation could be related to working memory which is thought to underlie the performance of the primary task as well as the mismatch task.

Limitations of the study

The brain regions described above might not be the only regions involved. Although no change in signal intensity was measured in other regions, those regions could still partake in the functional network. When no signal was detected in a certain area this could have resulted from the overall level of activation which did not change significantly during the performance of the task. Such a situation can occur when a certain region is involved in the processing of the standard as well as the deviant or in this case the 2-CRT task. An example involves areas related to working memory. Both the performance on the 2-CRT task as well as the execution of the mismatch detection task are thought to rely on working memory (see also Linden et al., 2003). Therefore, it can be expected that some areas cannot be made visible due to the high demand on these areas. It became clear in this study, that in further studies especially the timing of events should carefully be controlled in order to avoid obscuring activity due to functional overlap in certain regions that are involved in both tasks.

ERP and fMRI as complementary methods

Both EEG and fMRI have been used to investigate visual change detection. As both types of measurements are based on different physiological processes in the brain and each does therefore provide unique information on the occurrences, they are complementary in their usefulness. Each technique has its advantages. The measurement of electrophysiological changes in the brain provides the necessary temporal resolution allowing for the detection of components with millisecond precision. Only an ERP study can reveal the vMMN component and confirm that the paradigm is suitable to investigate change detection. fMRI used to measure changes in blood oxygenation, yields highly localised measures of brain activation with a good spatial resolution. Its temporal resolution, however, is significantly longer than the time needed for most perceptual and cognitive processes and certain fast and short processes will therefore remain obscured. In order to uncover the processes underlying visual change detection the use of both methods is inevitable.

An investigation of the relationship between impulsivity and change detection

In the third study the relationship between impulsivity and the ability to detect unexpected changes in the visual environment was investigated. Psychological concepts of impulsivity are not just limited to behavioural aspects of personality, but also include aspects on a more functional level, which can be described by cognitive characteristics. Definitions of cognitive impulsivity include high speed and a lack of control, or the fast, but imprecise use of information in perception and problem solving tasks. Kagan (Yando & Kagan, 1970) stated that the high speed in mental processing was the core cognitive characteristic of the impulsive personality. Other research using for example the Stroop task, the GoNogo task, or the Augmenting/Reducing paradigm has also shown that the differences between high and low impulsive personalities were likely to be related to differences in information processing. The inconsistencies in results between the investigations leave unclear which stage or stages of information processing are affected. One aspect of information processing which has barely been considered in relation to impulsivity is the non-intentional processing of incoming stimuli from the environment. According to Horvath et al. (2008) low amplitude measures indicate a bad detection of the deviant stimuli. To investigate whether impulsivity is related to this detection, scores from the impulsiveness subscale of the I7 (Eysenck), the BIS (Barratt and Patton), and behavioural measures of the GoNogo task are related to performance on the visual mismatch task. This has resulted in the hypothesised that lower amplitude measures of the vMMN are related to higher impulsivity scores, as an impulsive cognitive style is defined by fast, but not necessarily more precise processing.

A high score on the I7 impulsiveness scale has been associated with low amplitude measures of the vMMN. These results oppose the findings in the only other known study on MMN and impulsivity by Franken and colleagues (Franken et al. 2005). However, they have investigated auditory and not visual MMN in relation to impulsivity. The difference in results might be due to differences in the underlying processes necessary for visual change detection which are still unclear. Nevertheless, more detailed research needs to be carried out on the relationship between impulsivity and change detection in order to validate the results in the visual field.

In this study it has been established, that both vMMN amplitude and commission error rate are related to response speed (and impulsivity), but not to each other. Fast responses are related to low amplitude measures of the vMMN and a high rate of commission errors. As response speed is also strongly related to impulsivity the underlying factor seems to be fast and imprecise information processing causing a bad detection and a higher error rate. Since vMMN and error rate are not related it can be excluded that the same stage of information processing is responsible for bad mismatch detection and error rate. This conclusion is confirmed by results on GoNogo studies, demonstrating that commission errors are related to the response choice stage of information processing.

An explanation was sought by relating these results to Sander's cognitive-energetic model of information processing. According to this model bad detection of the deviant stimulus and errors made in the GoNogo task are results of different stages in information processing. The detection of deviants takes place in the first stage and the commission errors are related to failures in the information processing at a later stage. Therefore, a tentative conclusion can be drawn: impulsivity can be related to information processing with impulsivity having an effect at only one stage of information processing at one time.

Future investigations

The change detection system is capable of registering not only basic visual features like colour, spatial frequency, contrast, shape, movement direction, but also the conjunction of features, object-related changes and temporal regularities. So far though, the vMMN has only been elicited under laboratory conditions and no good example can be provided for its occurrence in an everyday situation. It still remains unclear what the actual neural representations look like and how comparison of the representations takes place. For future research on the vMMN it could be helpful to compare results with investigations of the phenomena of change blindness and inattention blindness. These phenomena have to do with the inability to see changes in complex natural visual scenes, although the subject is informed that changes will occur. One of the theories to explain such blindness suggests that "representations of considerable detail and sophistication" are present in the visual system, so-called proto-objects (Rensink, 2000). This might be a starting point to

search for the neural representation of information of the visual stream in mismatch detection.

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Appendix A

Edinburgh Handedness Inventory

Bitte geben Sie an, mit welcher Hand Sie die folgenden Tätigkeiten erledigen, in dem Sie das entsprechende Kästchen ankreuzen.						
		Immer links	Meistens links	Mal links, mal rechts	Meistens rechts	Immer rechts
1.	Mit welcher Hand schreiben Sie?	<input type="checkbox"/>				
2.	Mit welcher Hand kämmen Sie sich?	<input type="checkbox"/>				
3.	Mit welcher Hand zeichnen Sie genaue Skizzen?	<input type="checkbox"/>				
4.	Mit welcher Hand werfen Sie einen Ball?	<input type="checkbox"/>				
5.	Mit welcher Hand halten Sie eine Schere zum genauen Ausschneiden?	<input type="checkbox"/>				
6.	Mit welcher Hand halten Sie ein Streichholz beim Anzünden?	<input type="checkbox"/>				
7.	Mit welcher Hand halten Sie Ihre Zahnbürste beim Putzen?	<input type="checkbox"/>				
8.	Mit welcher Hand halten Sie ein Messer zum Brotschneiden?	<input type="checkbox"/>				
9.	Mit welcher Hand halten Sie einen Löffel zum Suppenessen?	<input type="checkbox"/>				
10.	Mit welcher Hand halten Sie einen Besen (obere Hand) beim kehren?	<input type="checkbox"/>				
11.	Mit welcher Hand heben Sie den Deckel von einer Dose ?	<input type="checkbox"/>				
12. Fand eine Umstellung der Händigkeit von links auf rechts statt?						
	Nein	Ja	wenn ja, wann?			
	<input type="checkbox"/>	<input type="checkbox"/>	_____			

Appendix B

I7 Fragenbogen

Anleitung

Bitte beantworten Sie jede Frage, indem Sie das JA oder das NEIN, das der Frage folgt, einkreisen. Es gibt keine richtigen oder falschen Antworten und keine Fangfragen. Bitte arbeiten Sie zügig und denken Sie nicht zu lange über die genaue Bedeutung der Fragen nach. Bitte achten Sie darauf, dass Sie jede Frage beantworten mit ein Kreis um die richtige Antwort

1.	Würde Ihnen Wasserskifahren Spaß machen?	Ja	Nein
2.	Bleiben Sie gewöhnlich lieber bei Produkten, von denen Sie wissen, dass sie zuverlässig sind, anstatt neue auszuprobieren, um möglicherweise etwas Besseres zu finden?	Ja	Nein
3.	Hätten Sie mit einem einsamen Fremden mitleid?	Ja	Nein
4.	Macht es Ihnen Spaß, schon mal ein Risiko einzugehen?	Ja	Nein
5.	Gehen Ihnen die Probleme Ihrer Freunde oft sehr nahe?	Ja	Nein
6.	Würde Ihnen Fallschirmspringen Spaß machen?	Ja	Nein
7.	Kommt es vor, dass Sie Dinge spontan kaufen?	Ja	Nein
8.	Ärgern Sie sich über unglückliche Menschen, die sich selbst bemitleiden?	Ja	Nein
9.	Tun und sagen Sie im allgemeinen Dinge, ohne vorher zu überlegen?	Ja	Nein
10.	Neigen Sie dazu, nervös zu werden, wenn andere um Sie herum nervös zu sein scheinen?	Ja	Nein
11.	Geraten Sie oft in Schwierigkeiten, weil Sie Dinge tun, ohne sie sich vorher zu überlegen?	Ja	Nein
12.	Glauben Sie, dass Per-Anhalter-Fahren eine zu gefährliche Art des Reisens ist?	Ja	Nein
13.	Finden Sie es albern, wenn Leute vor Glück weinen?	Ja	Nein
14.	Springen Sie im Schwimmbad gerne von hohen Sprungtürmen?	Ja	Nein
15.	Haben die Menschen, mit denen Sie zusammen sind, starken Einfluss auf Ihre Stimmung?	Ja	Nein
16.	Sind Sie ein impulsiver Mensch?	Ja	Nein
17.	Begrüßen Sie neue Erfahrungen und Empfindungen, selbst wenn sie etwas beängstigend und außergewöhnlich sind?	Ja	Nein
18.	Berührt es Sie sehr, wenn einer Ihrer Freunde traurig zu sein scheint?	Ja	Nein

19.	Denken Sie gewöhnlich erst sorgfältig nach, bevor Sie etwas tun?	Ja	Nein
20.	Würden Sie gerne lernen, ein Flugzeug zu fliegen?	Ja	Nein
21.	Versetzen Sie sich jemals tief in die Gefühle einer Person aus einem Film, Theaterstück oder Roman hinein?	Ja	Nein
22.	Tun Sie Dinge oft aus einem momentanen Gefühl heraus?	Ja	Nein
23.	Macht es Sie sehr betroffen, wenn Sie jemanden weinen sehen?	Ja	Nein
24.	Finden Sie das Lachen von anderen manchmal ansteckend?	Ja	Nein
25.	Denken Sie meistens gründlich nach, bevor Sie etwas sagen?	Ja	Nein
26.	Geraten Sie häufig in Situationen hinein, von denen Sie später wünschen, Sie kämen wieder heraus?	Ja	Nein
27.	Begeistern Sie sich manchmal so sehr für neue und aufregende Ideen, dass Sie mögliche nachteilige Folgen übersehen?	Ja	Nein
28.	Finden Sie es schwierig, Leute zu verstehen, die beim Bergsteigen Kopf und Kragen riskieren?	Ja	Nein
29.	Sind Sie in der Lage, Entscheidungen zu treffen, ohne sich über die Gefühle davon Betroffener Gedanken zu machen?	Ja	Nein
30.	Macht es Ihnen manchmal Spaß, Dinge zu tun, die ein bisschen beängstigend sind?	Ja	Nein
31.	Brauchen Sie viel Selbstkontrolle, um sich aus Schwierigkeiten herauszuhalten?	Ja	Nein
32.	Empfinden Sie eher Ärger als Mitleid, wenn Sie jemanden weinen sehen?	Ja	Nein
33.	Würden Sie zustimmen, dass fast alles, was Spaß macht, ungesetzlich oder unmoralisch ist?	Ja	Nein
34.	Gehen Sie lieber langsam in kaltes Meerwasser hinein, anstatt schnell hineinzutauchen oder hineinzuspringen?	Ja	Nein
35.	Sind Sie oft überrascht über die Reaktionen der Leute auf das, was Sie tun oder sagen?	Ja	Nein
36.	Würden Sie das Gefühl genießen, auf Skiern sehr schnell eine steile Bergabfahrt hinunterzufahren?	Ja	Nein
37.	Schauen Sie Leuten gerne beim Öffnen von Geschenken zu?	Ja	Nein
38.	Glauben Sie, dass Ausgehen am Abend mehr Spaß macht, wenn es nicht vorher geplant ist oder im letzten Moment organisiert wird?	Ja	Nein

39.	Wurden Sie gerne tiefseetauchen?	Ja	Nein
40.	Wurde es Ihnen sehr schwer fallen, jemanden schlechte Nachrichten zu Überbringen?	Ja	Nein
41.	Wurde Ihnen sehr schnelles Autofahren Spaß machen?	Ja	Nein
42.	Arbeiten Sie gewöhnlich schnell, ohne sich zu sehr zu bemühen, das Getane zu überprüfen?	Ja	Nein
43.	Andern sich Ihre Interessen häufig?	Ja	Nein
44.	Wägen Sie alle Vor –und Nachteile ab, bevor Sie sich für etwas entscheiden?	Ja	Nein
45.	Kommt es vor, dass die Probleme von Freunden Sie sehr betroffen machen?	Ja	Nein
46.	Wurden Sie gerne unterirdische Hohlen erforschen?	Ja	Nein
47.	Wurden Sie sich von einer Arbeit abhalten lassen, die schon mal ein bisschen gefährlich sein kann?	Ja	Nein
48.	Ziehen Sie es vor, eine Sache zu Überschlafen, bevor Sie eine Entscheidung treffen?	Ja	Nein
49.	Schreien Sie zurück, wenn Sie angeschrieen werden?	Ja	Nein
50.	Tun Ihnen Leute leid, die sehr schüchtern sind?	Ja	Nein
51.	Sind Sie fröhlich, wenn Sie mit einer lustigen Gruppe zusammen sind und traurig, wenn die anderen betrübt sind?	Ja	Nein
52.	Treffen sie Ihre Entscheidungen gewöhnlich schnell?	Ja	Nein
53.	Können Sie sich vorstellen, wie es sein muss, wenn man sehr einsam ist?	Ja	Nein
54.	Beunruhigt es Sie, wenn andere besorgt und unruhig sind?	Ja	Nein

Überprüfen Sie bitte noch mal ob sie alle Fragen beantwortet haben.

Appendix C

Barratt Impulsiveness Scale, 11th Revision

- | | |
|--|-------------|
| 1. Ich bereite mich auf meine Aufgaben und Pflichten sorgfältig vor. | -auswählen- |
| 2. Ich tue Dinge, ohne darüber nachzudenken. | -auswählen- |
| 3. Ich bin entschlossfreudig. | -auswählen- |
| 4. Ich bin sorglos. | -auswählen- |
| 5. Ich passe nicht auf. | -auswählen- |
| 6. Gedanken rasen durch meinen Kopf. | -auswählen- |
| 7. Ich plane einen Ausflug rechtzeitig im voraus. | -auswählen- |
| 8. Ich bin beherrscht. | -auswählen- |
| 9. Ich kann mich leicht konzentrieren. | -auswählen- |
| 10. Ich spare mein Geld. | -auswählen- |
| 11. Ich drücke mich vor Theaterbesuchen oder Vorträgen. | -auswählen- |
| 12. Ich bin ein gründlicher Denker/ eine gründliche Denkerin. | -auswählen- |
| 13. Ich kümmere mich um Sicherheit am Arbeitsplatz. | -auswählen- |
| 14. Ich sage Dinge, ohne darüber nachzudenken. | -auswählen- |
| 15. Ich mag es, über schwierige Probleme nachzudenken. | -auswählen- |
| 16. Ich wechsle meine Jobs. | -auswählen- |
| 17. Ich handle impulsiv. | -auswählen- |
| 18. Mir wird schnell langweilig, wenn ich über ein Problem nachdenke. | -auswählen- |
| 19. Ich folge meinen augenblicklichen Eingebungen. | -auswählen- |
| 20. Ich bin ein ausdauernder Denker/ eine ausdauernde Denkerin. | -auswählen- |
| 21. Ich wechsle meine Wohnung. | -auswählen- |
| 22. Ich kaufe Sachen spontan. | -auswählen- |
| 23. Ich kann nicht über zwei Dinge gleichzeitig nachdenken. | -auswählen- |
| 24. Ich wechsle meine Hobbies. | -auswählen- |
| 25. Ich gebe mehr Geld aus, als ich verdiene. | -auswählen- |
| 26. Wenn ich nachdenke, kommen mir oft nebensächliche Gedanken
in den Sinn. | -auswählen- |
| 27. Ich kümmere mich mehr um die Gegenwart als um die Zukunft. | -auswählen- |
| 28. Im Theater oder bei Vorträgen werde ich unruhig. | -auswählen- |
| 29. Ich mag Puzzles und Geduldspiele. | -auswählen- |
| 30. Ich bin zukunftsorientiert. | -auswählen- |

Abbreviation List

2-CRT	2 choice response time task
ACC	anterior cingular cortex
BAS	behavioural activation system
cpd	cycles per degree
CPT	continuous performance task
deoxyHb	deoxyhaemoglobin
DLPFC	dorsolateral prefrontal cortex
DRC	deviance related component
EEG	electroencephalography
ERP	event related potential
fMRI	functional magnetic resonance imaging
FOV	field of view
HEOG	horizontal electrooculogram
I7	Impulsiveness Questionnaire by Eysenck
IVE	Impulsiveness-Venturesomeness-Empathy Scale by Eysenck
LGN	lateral geniculate nucleus
m	mean
MMN	mismatch negativity
MRI	magnetic resonance imaging
ms	millisecond
mV	millivolt
oxyHb	oxyhaemoglobin
PCC	posterior cingular cortex
RF	radio frequency
rIFG	right inferior frontal gyrus
RT	reaction time
sd	standard deviation
SMA	supplementary motor cortex
TE	echo time
TPJ	temporoparietal junction
TR	repetition time
VEOG	vertical electrooculogram
VLPFC	ventrolateral prefrontal cortex
vMMN	visual mismatch negativity

Summary

This thesis presents a study of the visual change detection mechanism. This mechanism is thought to be responsible for the detection of sudden and unexpected changes in our visual environment. As the brain is a capacity limited system and has to deal with a continuous stream of information from its surroundings only a part of the vast amount of information can be completely processed and be brought to conscious awareness. This is information, which passes through attentional filters is used for goal-directed behaviour. Therefore, the change detection mechanism is a very useful aid to cope with important information which is outside the focus of our attention.

It is thought that a neural memory trace of repetitive visual information is stored. Each new information input is compared to this existing memory trace by a so-called change or mismatch detection system. Following a sudden change, the comparison process leads to a mismatch and the detection system elicits a warning signal, possibly followed by an orienting response can follow. This involves a change in the focus of attention towards this change which can then be evaluated for potential danger and allows for a behavioural adaptation to the new situation.

To this purpose a paradigm was developed combining a 2-choice response time task with in the background a mismatch detection task of which the subjects were not aware. This paradigm was implemented in an ERP and an fMRI study and was used to study the the change detection mechanism and its relationship with impulsivity.

In previous studies a change detection system for auditory information had already been established. As the brain is a very efficient system it was thought to be unlikely that this change detection system is only available for the processing of auditory information.

Indeed, a modality specific mismatch response at the sensory specific occipital cortex and a more general response at the frontocentral midline, which both resemble the component in auditory research were found.

Additionally, magnetic resonance imaging revealed a possible functional network of regions, which responded specifically to the processing of a deviant. These regions included the occipital gyrus, premotor cortex, inferior frontal cortex, thalamas, insula, and parts of the cingular cortex.

The relationship between impulsivity measures and visual change detection was established in an additional study. More impulsive subjects showed less detection of deviant stimuli, which was most likely due to too fast and imprecise information processing.

To summarise, the work presented in this thesis demonstrates that the aim of this study has been achieved: Visual mismatch negativity was established, a number of regions were associated with change detection and also its relevance in information processing was shown.

Erklärung

Hiermit versichere ich, Christine M. Smit, dass die Dissertationsschrift mit dem Titel

„An analysis of visual mismatch and its relationship to impulsivity.“

von mir selbständig erstellt wurde. Ich habe keine außer den angegebenen Quellen und Hilfsmitteln verwendet und die aus fremden Quellen direkt oder indirekt übernommenen Gedanken als solche gekennzeichnet. Die vorliegende Arbeit wurde in gleicher oder ähnlicher Form bisher weder veröffentlicht noch einer anderen Prüfungskommission vorgelegt.

Trier, den 28. Juli 2008

Christine M. Smit