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Change Blindness and Cueing

The role of attention and memory in visual search

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Abstract

Change blindness is the relative inability to detect changes between visual scenes when the transient change signal is occluded (Simons, 2000). To detect changes between scenes visual attention is necessary to form stable representations in visual memory, which can then be compared. The dissertation at hand is designed to study the influence of (especially semantic) cueing on visual attention and memory in the change blindness phenomenon using behavioural and electrophysiological data. The five experiments showed that cues that exogenously capture attention influence change detection and the formation of stable visual representations of the pre- and post-change scene explicitly and implicitly. These exogenous cues are efficient if they are semantic or perceptual and they interact depending on the possibility to semantically categorize the visual scene. This range of possible exogenous cue types seems to show that the human system searches for exogenous (semantic) cues to guide visual search. The experiments also revealed signs for an automatic attentional mechanism that may underlie the detection of changes. Furthermore the results found here challenge theories that explain change blindness due to representation failures (for reviews, see Rensink, 2000; Simons & Rensink, 2005).

Change Blindness and Cueing:

The role of attention and memory in visual search

Our world is a visual world. Sight is our primary sensory facility (Hershberger, 1992; Schurr et al., 1996). Our life is a constant influx of information. Hershberger states that vision is the “primary sense for obtaining information” (1992, p.509). Obtaining information in visual search is not only crucial for many occupational groups but extremely relevant in daily life for example while driving a car or shopping for food. While shopping in a supermarket we have to search visually for the products we need or want in an environment full of similar objects. While driving a car we have to monitor traffic, traffic signals, and pedestrians and watch out for unexpected objects or events. The same importance of visual search can be found in other settings. Air traffic controllers have to constantly monitor a visual array to regulate air traffic (Remington, Johnston, Ruthruff, Gold, & Romera, 2000). Pilots are faced with a cockpit which is highly complex and in which it is crucial to monitor many readouts and search for deviations from the standard (Perrott, Sadralodabai, Saberi, & Strybel, 1991). In the following dissertation the relationship between attention and visual memory (especially for semantic stimuli/settings) is researched with a visual search paradigm: change blindness.

Attention and memory in visual search

When we navigate our visual world we are under the assumption that we have a detailed, relatively complete representation of our environment. Nevertheless our perception is not quite so complete or explicit as is our impression (Rensink, O'Regan, & Clark, 1997). The literature concerning attention states that mainly information in the focus of attention is processed and other information is filtered out (see Broadbent, 1958; Treisman, 1964). According to Baddeley and Hitch (1974) we can hold 7 +/- 2 information/chunks in our working memory and therefore ready for conscious manipulation (Conway & Engle, 1996; Engle, 2002; M. Treisman, 1985). This seems a relatively small amount of information bearing in mind the complexity of our visual environment. Sperling (1960) conducted a series of iconic memory experiments in which he presented his subjects with for example a three*three letter matrix for 15-500 ms and instructed them to recall as many as possible. Subjects were only able to recall in average 4.3 items in this free recall condition. If Sperling cued one of the three lines subjects were able to recall all three items in the cued line. Therefore Sperling reasoned that all letters were stored in an iconic memory that influences recall/recognition for up to a second. Afterwards performance is reduced to the level of free recall (Coltheart, 1980; Sperling, 1960). We thus might store a great amount of information about our visual environment for a short time but can only access a small amount of this information for processing before it disintegrates (Luck & Hollingworth, 2008; Todd & Marois, 2004)

Change Blindness (figure 1)

A class of paradigms that enables one to study visual search in its completeness, or rather incompleteness, is change blindness. Change blindness is the relative inability to detect changes which occur between visual scenes (Simons, 2000). The change itself generates a transient signal when it occurs (as can be seen in the comparison of original and modified picture of figure 1). Attention is drawn to this single transient signal and the change is detected (Becker, Pashler, & Anstis, 2000). In the change blindness paradigm this change transient is occluded by multiple other transients or continuous changes that do not create an easily perceivable transient signal. Thus attention is not captured by the change transient alone (as can be seen in comparison of the original and modified picture with mudsplashes of figure 1).

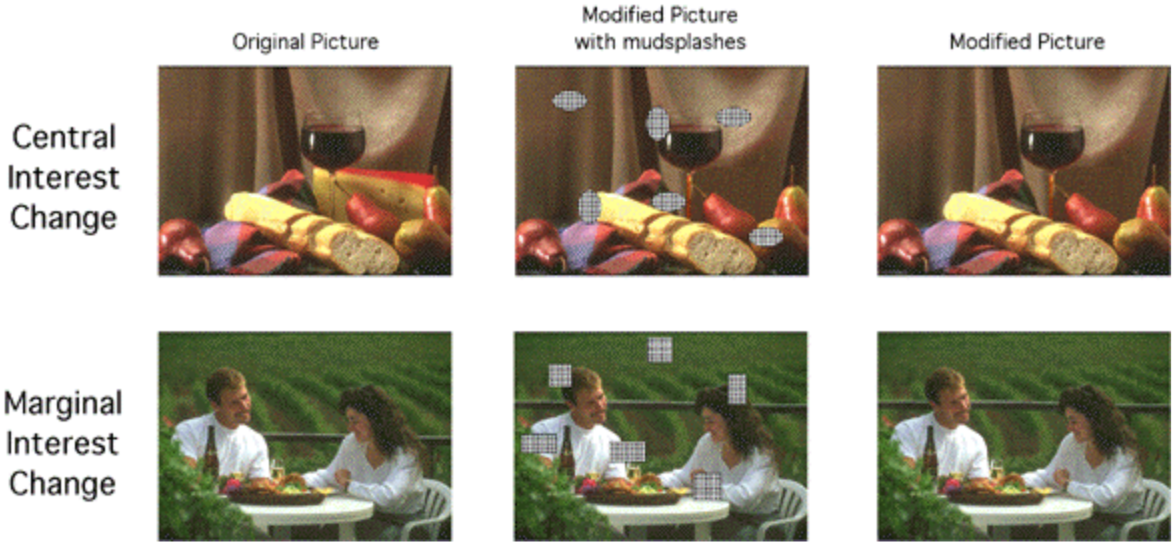


Figure 1. Figure from supplementary materials of “Change blindness as a result of ‘mudsplashes’” by O’Regan, Rensink & Clark (1999), *Nature, 398*. Copyright 1999 by Nature Publishing Group, with permission from J. Kevin O’Regan. Illustration of the change blindness paradigm with the example of mudsplashes as multiple transients occluding the change transient.

In the following experiments the change blindness phenomenon is used to study the relation of attention and memory in visual search. Therefore, I will at first review the experimental research on change blindness, especially the conditions under which change blindness occurs and the theories explaining the mechanisms underlying this phenomenon. I will furthermore review the relation of change blindness with attention, visual memory and consciousness. Concluding the review on the current state of research I will present the results of neurobiological studies on the event related potentials evoked by change blindness/change detection as well as the neural correlates of change detection. Subsequently, I will introduce my research questions derived from the current state of the literature on change blindness.

Experimental research on change blindness

Ways to occlude the change transient

The occlusion of the change transient can be achieved by different techniques. Commonly a blank screen inserted between the original and modified scene produces a global transient. The appearance of the modified scene after the blank produces transient signals for all objects in the scene rather than only for the change (Becker et al., 2000). The same is true for changes made during saccades or eye blinks (Grimes, 1996; Henderson, Weeks, & Hollingworth, 1999; McConkie & Currie, 1996a, 1996b), the presentation of mud splashes (O'Regan et al., 1999), scene cuts (Levin & Simons, 1997), or other transients (O'Regan et al., 1999; Rensink, O'Regan, & Clark, 2000). Another way to avoid a change transient to be detected is a continuous change. Is the change slow enough (over seconds rather than milliseconds) the transient does not capture attention (Simons, Franconeri, & Reimer, 2000).

Ways to present the change (figure 2)

In the flicker paradigm the original and modified scene are presented alternately disrupted by the global transient until the change is detected or a time limit is arrived (Rensink et al., 1997). The one shot flicker paradigm does present the original and modified scene only once (Levin & Simons, 1997). This paradigm is used in real world change blindness studies (Varakin, Levin, & Collins, 2007).

Ways to design the scenes

The original and modified scene can be designed on different levels of complexity and reality (Rensink, 2002). Scenes can be constituted from a few simple geometrical forms (Koivisto & Revonsuo, 2003), line drawings (M. R. Beck & Levin, 2003) to photos of real objects (Zelinsky, 2003), scenes (O'Regan et al., 1999) or films (Levin & Simons, 1997).

Furthermore the displays can be dynamic (Triesch, Ballard, Hayhoe, & Sullivan, 2003) up to real world interactions (Varakin et al., 2007).

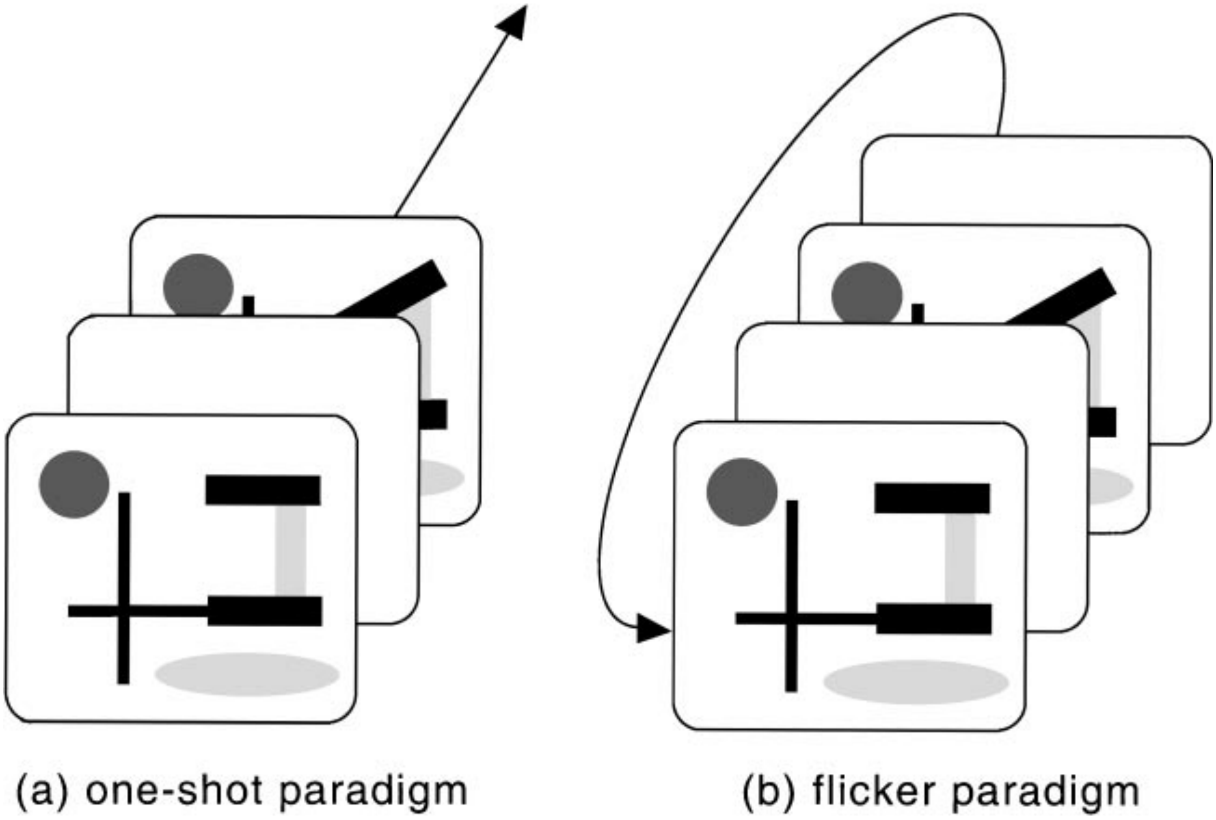


Figure 2. Figure from "Change detection" by Rensink (2002), *Annual Review of Psychology, 53*, p. 253. Reprinted by permission from Macmillan Publishers Ltd: Annual Review of Psychology, copyright (2002), with permission from Ronald A. Rensink. Presentation of the different change blindness paradigms. (a) One-shot paradigm; each display is presented once before a change decision is to be made. (b) Flicker paradigm; original and modified scene are presented alternately until a detection decision is made or the time limit expired.

Ways to make a change

There is a wide variety of change types (Rensink, 2002). Rensink reviews four types:

(a) Existence – stimuli can appear or disappear

(b) Properties – stimuli features like colour, orientation, luminance, etc. can change

(c) Identity – a stimuli can be changed into another stimuli

(d) Layout – spatial configurations in the display can change

Ways to instruct the participants

Change blindness tasks also differ in the intentionality ascribed to the change detection. Tasks can be intentional (instructing subjects to detect the change) or incidental (no instruction for change detection) as well as a hybrid (dual task) where another task is primary although participants are instructed to report detected changes (Rensink, 2002). In addition, participants can be instructed to report the occurrence of a change, the localization of a change or the identity of the change (Rensink, 2002). The basis for report of a change can also differ from explicit conscious perception of the change over the sensing of a change without a conscious percept (so called mindsight; Rensink, 1998) to implicit perception that can be inferred from subsequent forced choice or priming tasks.

Interaction of experimental design and amount of change blindness

The experimental conditions that can be used in change blindness studies have a great influence on the occurrence of change blindness. In his review Rensink (2002) states evidence that the amount of change blindness rises linearly with the complexity of the setting, and task as well as with the demands of the paradigm and the change. A more complex setting (e. g. higher number of objects, more realistic scenes, and dynamic scenes) seems to be more difficult and thereby results in more failures to detect the change. The same is true for the task: identification requires not only the detection but also additional information about the changed stimuli thereby being more difficult. The paradigm also modulates change blindness through the limited possibility to detect the change in the one-shot flicker paradigm as compared to the flicker paradigm as does the technique used to occlude the change transient. Techniques that completely occlude the transient and render all objects as transients with presentation of the post-change scene (eye-blink, blank screen, etc.) result in higher change blindness than techniques occluding only part of the scenes like mudsplashes.

On the other hand, Rensink (2002) reviews evidence that every feature in a change blindness experiment that allocates attention decreases the amount of change blindness. This includes changes to unique features or uncommon changes (for example, changes to the existence of an object are uncommon in real life) as well as changes to moving objects. These changes are able to allocate attention through their singularity or motion vector. The semantic relevance or saliency of objects (dependent on knowledge, memory, and expectations or expertise. see Simons & Ambinder, 2005) is also able to allocate attention and reduce change blindness (see experiments on central and marginal interest changes, Rensink et al., 1997). That decrease of change blindness can also be found for conditions that actively demand attention to be applied to change detection or the change location like the instruction to intentionally search for a change or the introduction of cues in the paradigm.

Hence, it seems that conditions, which complicate the allocation of attention to the change through complexity or difficulty, enhance change blindness and conditions that attract attention decrease change blindness.

Theories of change blindness

On the ground of results obtained in change blindness studies, theories are developed that strive to explain scene perception or visual memory formation and their dependence on attention. These theories can be divided in ones that state representation failures and ones that state comparison failures to be the reasons for change blindness. The following experiments strive to research the role of attention and visual memory for visual search and answer the question what mechanisms underlie change blindness.

Coherence theory

Rensink (2000) strives to explain the underlying mechanism of change blindness in his coherence theory. According to coherence theory attention binds object features and forms a coherent representation as long as attention is allocated on the object. With the withdrawal of attention this representation is unbound. Furthermore Rensink (2000) claims that the formed representations do not accumulate in a sustained scene representation. According to the lack of stored representation only the object in the current focus of attention can be used for change detection. Changes to objects that are not attended at the time of the global transient cannot be detected because no sustained representation is formed whatsoever and thus cannot be used for change detection. Hence, Rensink argues that focussed attention is crucial for visual search.

Involvement of visual memory

Hollingworth (2006) argues against the complete lack of sustained representation formulated in coherence theory and proposes the involvement of visual short- and long-term memory in visual information processing. Memory for visual information contains four different stores: 1) visible persistence, 2) informational persistence, 3) visual short-term memory, and 4) visual long-term memory (Hollingworth, 2006). Visible persistence represents the visual information as sensed for an extremely short time (80-100 ms) whereas informational persistence is somewhat longer (150-300 ms) but does not represent the information visible. Informational persistence describes a mechanism able to extract information from the presented stimulus for 150-300 ms after the offset of said stimuli (G. R. Loftus & Irwin, 1998). Both memory stores are said to be the constituents of iconic memory (Coltheart, 1980). The visual short-term memory stores abstracted visual information and in contrast to working memory is limited to holding 3-4 objects active at a time. The abstraction of information results in a reduced sensitivity to spatial information and feature details. Visual long-term memory also holds abstracted representations but can accumulate visual information from a great number of single objects in contrast to the limited number of 3-4 objects in the visual short-term memory (Hollingworth, 2004, 2005). In contrast to visible and informational persistence the abstracted representation in visual short- and long-term memory are less susceptible to interference and can be maintained across a longer time span and across saccades (Hollingworth, 2006). According to Hollingworth's theory, attention allocation is the principle with which formation of representations is enabled. The information in the focus of attention is encoded and can be transferred into visual memory stores. Thus, attention allocation is a necessary but not sufficient prerequisite for representation formation. Hollingworth presents empirical evidence for the persistence of visual information no longer in the focus of attention in the visual short- and long-term memory. Hollingworth and colleagues conducted experiments in which objects no longer in the focus of attention (as controlled through eye movement monitoring) were changed (Hollingworth & Henderson, 2002; Hollingworth, Williams, & Henderson, 2001). Although, according to coherence theory, no memory of the pre-change object should be evident because attention was withdrawn prior to the change, results showed sustained representation in change detection rates and recognition tasks (Hollingworth & Henderson, 2002; Hollingworth, Williams, et al., 2001). Busch (2013) conducted an experiment in which he was able to show with event related electrophysiological components that even under change blindness visual representations of both the pre- and post-change object are stored although the recognition is severely reduced as compared to change detection trials.

Hollingworth argues that the transiency of visual information proposed by Rensink's coherence theory is only evident for visible and informational persistence. If the visual representations are stored in the higher-level memory stores (as is evident from the results found by Busch, 2013) why does change blindness occur? Hollingworth assumes the principles for change detection are representation failures (the critical information is not encoded) or comparison failures (the representations are sufficient for change detection but are not compared).

Summary of models assuming comparison or representation failures (figure 3)

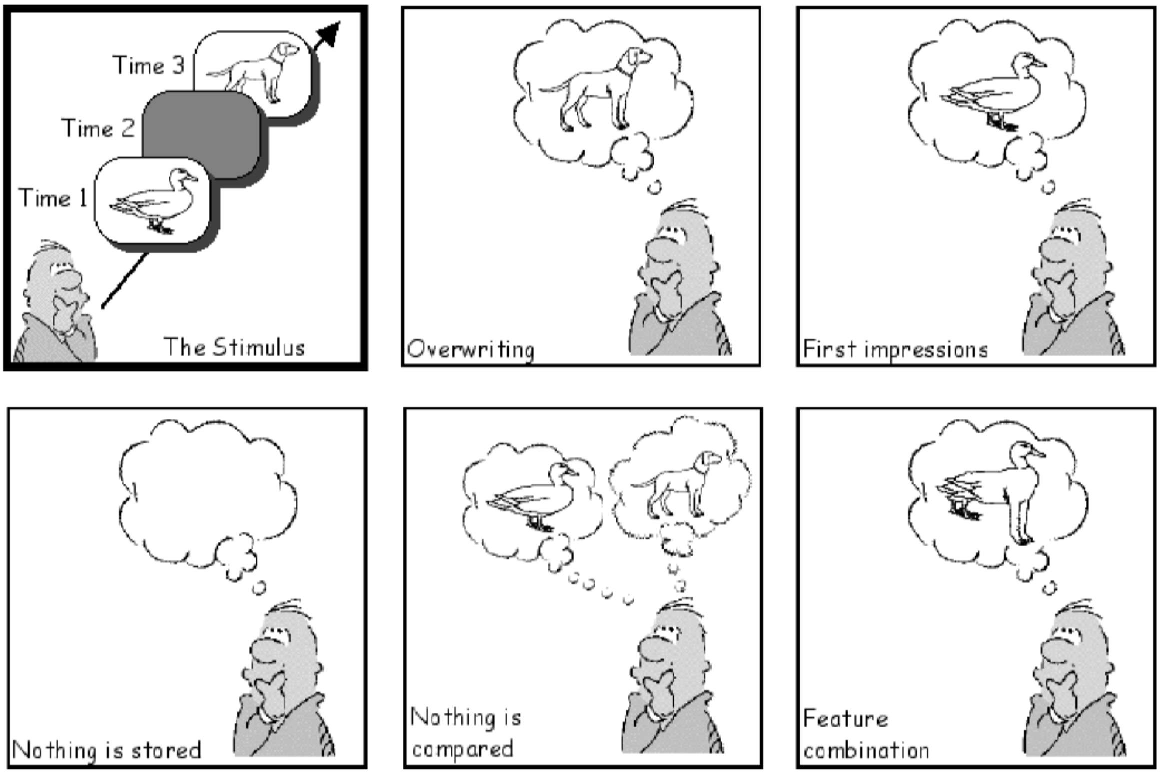


Figure 3. Figure from “Current approaches to change blindness” by Simons (2000), *Visual Cognition, 7*, p. 9. Copyright 2000 by Routledge, with permission from Daniel J. Simons. The possible causes for change blindness depending on representation and comparison failures.

According to these two principles, Simons discussed five possible reasons for change blindness in his review (2000):

(a) Nothing is compared between the original and modified scene.

(b) Nothing is stored from the two scenes.

(c) Feature combination in which the change is not detected because both stimuli are merged.

(d) First impression, where the representation of the original scene is preserved and the modified scene is not updated.

(e) Overwriting of the representation of the original scene with the modified scene.

Nothing is compared

Simons argues that according to the iconic memory literature both scenes are completely stored but they are not compared. This could be due to our normal experience of a continuous, consistent world in which stimuli are not changed in the blink of an eye. Hence, under the assumption of stability the system does not compare the scenes. Support for this view comes from studies showing that details from the original and modified scene are represented (Yeh & Yang, 2009) and the occurrence of change blindness.

Nothing is stored

In accordance with Rensink's coherence theory, this model proposes that we do not store visual information but use the visual world as an external information store (Rensink et al., 2000). Due to the studies showing memory for details from the pre- and post-change scene (Yeh & Yang, 2009) as well as the studies reviewed by Hollingworth (2006) it seems unlikely that no information is stored. According to Simons a less absolutistic form of the argument states that only abstract information is stored from visual scenes (Simons, 1996). To reliably show evidence for the *nothing is stored* hypothesis, four requirements have to be met according to Simons and Rensink (2005). All four requirements deal with the possibility that the results can be explained in terms of the *nothing is compared* hypothesis with existing representations from the pre- and post-change scene as illustrated in figure 4.

Evidence has to make sure that decay or replacement of a previously stored representation is not responsible for the found results. The possibility has to be ruled out that the results are due to the storage of pre-change representations in a location, path or format not accessible for comparison. The alternative has to be eliminated that representations are comparable but simply are not compared as stated in the *nothing is compared* hypothesis.

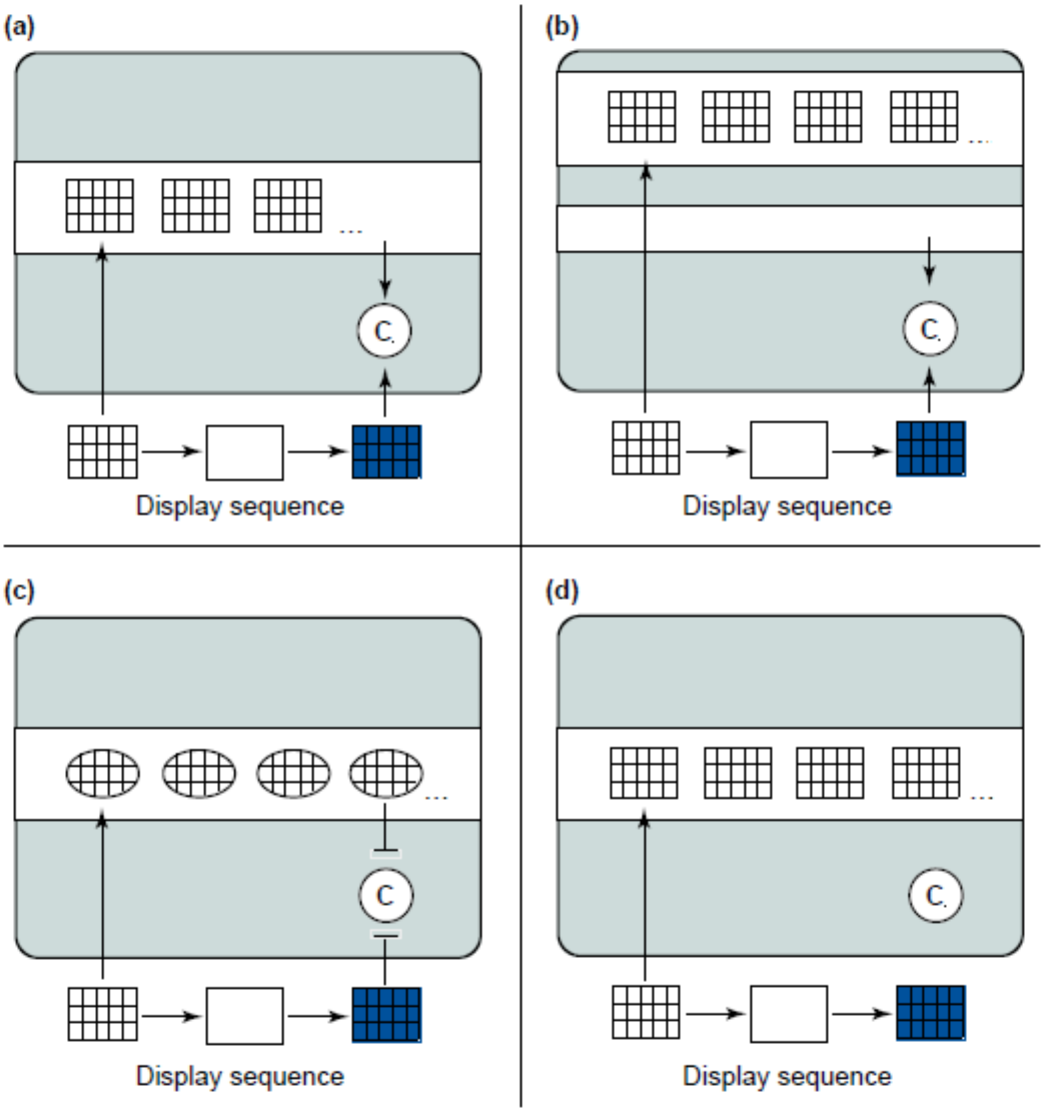


Figure 4. Figure reprinted from “Change blindness: past, present, and future” by Simons and Rensink (2005), *Trends in Cognitive Sciences, 9*, p. 18, copyright (2005), with permission from Elsevier and Donald J. Simons and Ronald A. Rensink. The figure shows possibilities that have to be eliminated in order to conclude on the failure to represent visual

scenes sufficient for change detection. a) Pre-change representation already decayed or is replaced, b) pre-change representation is localized or stored in pathways not accessible for comparison, c) pre- and post-change representations formats are not comparable, and d) pre- and post-change representations are comparable but are not compared.

Feature combination

The combination of features from the original and modified scene into a consistent representation seems plausible in light of literature from illusionary conjunctions (Treisman, 1993) or eyewitness studies (E. F. Loftus, 1979). Nevertheless Simons states that according to this hypothesis the combined features have to be consistent with the perceptual or semantic design of the scenes or the combination will not work. This however seems questionable for most forms of changes used in change blindness studies like appearance/disappearance of stimuli (Simons et al., 2000), changes of identity (Hollingworth & Henderson, 2000), and rotation or mirroring of stimuli (Hollingworth, Schrock, & Henderson, 2001).

First Impression

The model states that the representation of the first scene is processed and if the semantic properties of the modified scene remain constant the representation is not updated. Studies support this view, which show, that recollection of scene details is better for pre-change stimuli (Yeh & Yang, 2009). Support for the first impression hypothesis is rare and depends on similarity between pre- and post-change object and consciousness of the change (Yang & Yeh, 2009; Yeh & Yang, 2008).

Overwriting

Overwriting is the antithesis to first impression. According to this model, the modified scene is represented and overwrites the representation of the original scene. Merely abstracted information from the original scene could be compared with the representation of the modified scene. The blank or the modified scene thus acts as a visual mask of the original scene (Kahneman, 1968) and prevents comparison. The overwriting model gains much support from studies in which stimuli have to be identified and result in higher recollection rates of the post-change stimuli. The predominant part of the studies supports the overwriting hypothesis (M. R. Beck & Levin, 2003; Brawn, Snowden, & Wolfe, 1999; Busch, 2013; Landman, Spekreijse, & Lamme, 2003; Mitroff, Simons, & Levin, 2004; Rensink, 2000; Simons, 2000).

Implication of change blindness for related processes

The change blindness phenomenon can be used to study a variety of cognitive processes like attention, visual processing or scene perception as well as memory and consciousness.

The theories concerning the underlying mechanisms of change blindness assume on one hand that attention is central for change detection (Simons & Ambinder, 2005) and that the failure to detect changes can be attributed either to failures to compare sustained representations or the failure to form such representations. Hence, change blindness might be especially suited for research on visual memory and attention. To reliably discern global mechanisms of visual memory and/or attention it is important to carefully design the experiment (Simons & Rensink, 2005). According to these authors the modulation of change blindness by the complication or simplification of attention allocation sheds light on the role of attention for visual search. Thus, this paradigm can be used to discern which objects and what features of objects are attended to thereby inferring on the locus of attention and on attention scan paths as well as feature binding (Busch, Fründ, & Herrmann, 2010; Simons & Rensink, 2005). Furthermore the relation of attention and awareness can be researched: Is the attention on the change sufficient for change detection? Can changes outside the focus of attention be detected?

Another line of research change blindness contributes to, is visual processing and scene perception. Change blindness can enable insights into stimulus grouping mechanisms, categorization or foreground/background segregation (Simons & Rensink, 2005).

Interaction of procedure and visual memory

As stated above the conditions used in a change blindness experiment from the paradigm over the setting and the change type to the task modulate the amount of change blindness found. The relevance of procedure for possible conclusions on the formation of visual representations is demonstrated in the comparison of different paradigms. The predominance of studies supporting overwriting might be an artefact of the time course of most change blindness experiments. In the one-shot flicker paradigm both scenes are presented once with the global transient in between (this is also the paradigm used in real world change blindness experiments, see Simons & Levin, 1998). In the one-shot flicker paradigm the time course favours the overwriting hypothesis. To test the prevalence of the pre- or post-change scene representation a subsequent recall or recognition task is presented (M. R. Beck & Levin, 2003; Varakin et al., 2007). Thus the time lag between original scene and recall/recognition task is longer than between modified scene and recall/recognition task. Accordingly a recency effect is likely to take place that favours the representation of the post-change scene (Broadbent & Broadbent, 1981).

Unfortunately, to my knowledge the stability of representations are researched neither in the flicker paradigm nor the continual change paradigm. Nevertheless the recency effect should be evident for continual changes without visual disruption where the change is presented at the end of the trial and should therefore be rather available for recall/recognition than the initial configuration. In the flicker paradigm both scenes are presented alternately with the transient until the change is detected or the time limit is exceeded. In this paradigm mixed results should be found. Dependent on the image presented when the change is detected either the representation of the original or modified scene is the most recent and should show facilitated recall/recognition.

Apart from the question which reason might be responsible for the change blindness found in a certain task it remains also questionable if only one cause is evident in a given task. Varakin, Levin, and Collins (2007) reported that in a single experiment more than one reason for change blindness is evident. They used a real-world “one-shot” flicker paradigm to reveal if comparison or representation failures cause change blindness. Subjects in their experiments were presented with a folder of a certain colour and an obscured word. They were asked to close their eyes and imagine the word. While their eyes were closed (5-10s) the folder was swapped with a similar folder of a different colour. The authors subsequently tested memory for the font of the word and the colour of the folder. For participants exhibiting change blindness, poor memory of both features would be a sign for “global representation failure” where no information is represented. Recognition of the font but not the colours would speak for a “circumscribed representation failure” of the relevant changing feature. If the colours are recognized a “comparison failure” is evident. Varakin et al. (2007) found that subjects stating high confidence levels in the recognition task showed memory for the colours as well as the font, whereas low confidence subjects recognized the font but not the colours of the folders. Hence, the authors concluded that circumscribed representation failures as well as comparison failures could be evident in the same task.

Interaction of consciousness and visual memory

It is important to note that the high confidence subjects recognized the pre- as well as the post-change colour. According to the recency effect the one shot flicker paradigm used in the Varakin et al. study however should result in higher recognition rates for the post-change colour. There is an important difference between the studies supporting overwriting and the experiments conducted by Varakin et al. (2007). The differentiation between participants detecting the change and change blind participants is not done in the studies supporting the prevalent representation of the post-change item. Thus it is likely to assume that the participants who detected the change show a facilitated representation of the post-change item. This can be explained with the relevance and saliency of the post-change item for participants consciously detecting the change. The post-change item poses a mismatch signal that is detected and therefore is relevant and salient for the task. Todd and Marois (2004) showed that these features are important in light of the limited capacity of the visual short-term memory and that salience/relevance and explicit detection are correlated with the same neurological locus (intraparietal cortex). Yeh and Yang (Yang & Yeh, 2009; Yeh & Yang, 2008, 2009) investigated the influence of detection on the representation of the pre-change scene. According to their results the pre-change representation is not weakened under change detection (repetition priming) but the conscious access is blocked (recognition). The authors measured the representation of the pre-change scene with a repetition priming paradigm which is able to reveal storage of the representation without relying on conscious access to the representation. In the repetition priming paradigm participants have to name an object, which is either a repetition of a stimulus from the pre-change scene, from the post-change scene or a new stimulus. The participants are significantly better (faster, more accurate) at naming repeated objects independent of conscious access to scene representations. To measure conscious access to the scene representation participants were instructed to recognize which one of several stimuli stemmed from the pre or post-change display assuming that participants have to consciously access represented information to recognize the previously presented stimulus. Yeh and Yang (Yeh & Yang, 2008, 2009) conclude from their experiments the existence of a retrieval blocking mechanism from the post-change representation to conscious access of the pre-change representation. Therefore, results in line with overwriting (M. R. Beck & Levin, 2003) might be due to retrieval blockage rather than pre-change representation failure.

It is clear that attention and visual memory interact in visual search as reflected in the change blindness paradigm and that implicit processes complicate the interpretation of results. A method able to help clarify open questions is the analysis of neurobiological recordings.

Neurobiology of change blindness

The experiments presented in here are designed to research attention and memory processes in visual search. This is done through a combination of change blindness with word processing, cueing and contextual learning. Thus it is quite possible that implicit processes play an important role in the visual search task and electrophysiological data (EEG) is recorded to help the interpretation of behavioural results.

To interpret the electrophysiological data it is important to know which event related potentials (ERP) are associated with visual search processes in the change blindness phenomenon. Thus the following section reviews the results of change blindness studies using EEG or brain imaging techniques. Research on the neurobiology of change blindness mainly focuses on the distinction between detection and change blindness. Electrophysiological studies found modulation in early components associated with attention and later components associated with awareness or confidence. Studies designed to determine the electrophysiological correlates of change blindness and change detection analyse components elicited in trials in which participants indicate detection and those in which they fail to do so.

ERP components found in change detection trials

Early components and attention.

Detection involves modulation of early negative shifts between 100 and 300 ms after stimulus onset (Fernandez-Duque, Grossi, Thornton, & Neville, 2003; Koivisto & Revonsuo, 2003) or even earlier as Eimer and Mazza (2005) were able to show through a modulation of the contingent negative variation. The authors interpret these early modulations as an expression of attention allocation (Busch, Dürschmid, & Herrmann, 2010; Fernandez-Duque et al., 2003; Koivisto & Revonsuo, 2003; Störmer, McDonald, & Hillyard, 2009) or preparation processes (Eimer & Mazza, 2005). These attentional processes seem to be necessary but not sufficient for visual awareness although the event related components might reflect phenomenal visual awareness (Block, 2001; Koivisto & Revonsuo, 2003). Apart from these modulations in the N1 time interval, Busch, Dürschmid, and Herrmann (2010) also found a change related positivity in the P1 time interval. This is reflected in the literature on the early ERP components P1 and N1 (Eimer, 1993; Mangun & Hillyard, 1991; Vogel & Luck, 2000). These components are said to reflect a sensory gating mechanism for attended stimuli (Mangun & Hillyard, 1991). According to Rensink's (2000) and Hollingworth's (2006) theories of change blindness stated above it is clear that modulation of early ERP components associated with attention has to be found in the detected trials. According to Rensink's coherence theory attended objects are the only ones in which a change can be detected due to the impossibility of sustained representations. Hollingworth's visual memory theory states that attention allows objects to be transferred into visual short- or long-term memory as sustained representations. Apart from the assumptions concerning the possibility of sustained visual representations, both theories state that the allocation of attention is a necessary precondition for change detection.

Another component associated with attentional allocation is the N2pc (Schankin & Wascher, 2007, 2008). The N2pc is elicited contralateral to an attended location/stimuli and is able to reflect attentional shifts (Schankin & Wascher, 2007, 2008). Not surprisingly detected trials are also found to modulate the N2pc (Busch, Dürschmid, et al., 2010; Eimer & Mazza, 2005). Furthermore the N2pc seems to be exclusive for trials in which the change is not only detected but also identified (Busch, Fründ, et al., 2010). Busch et al. (2010) explain that the difference between detection and identification of a change might be in the feature binding. The detection of a change without the possibility to identify it (sensing a change as termed by Rensink, 2004) might be due to transient signals that are detected from single unbound object features. The N2pc seems to reflect the feature binding of these single object features containing the detected transient signal that allows the focussing of attention on the object that has changed and subsequently its identification (Busch, Fründ, et al., 2010).

Late component and mismatch detection.

The component most consistently found in change detection trials is the P3 (Eimer & Mazza, 2005; Fernandez-Duque et al., 2003; Koivisto, Kainulainen, & Revonsuo, 2009; Koivisto & Revonsuo, 2003; Niedeggen, Wichmann, & Stoerig, 2001). This component is said to reflect context updating (Donchin, 1981), because it is enhanced by the mismatch between a stored standard and the current percept (Niedeggen et al., 2001), especially when one is aware of this mismatch (Aru & Bachmann, 2009; Koivisto et al., 2009; Koivisto & Revonsuo, 2003). It is nevertheless not clear if the P3 reflects consciousness (Koivisto & Revonsuo, 2003), decision processes (Eimer & Mazza, 2005) or attention allocation processes as well as the early components found for detected trials (Busch, Dürschmid, et al., 2010; Niedeggen et al., 2001). The modulation of the P3 in change detection trials induced Koivisto and Revonsuo (2003) to assume that this component reflects access consciousness to the change. Eimer and Mazza (2005) on the other hand argue that this component is associated with the confidence level with which participants answer. They were able to show that confident decisions elicited the P3 and that confidence is much higher in change detection trials than in change blindness trials. Niedeggen, Wichmann and Stoerig (2001) argue that the P3 reflects the allocation of attention to the mismatch signal evoked by the comparison of a stored representation with the current percept and thereby able to lead to conscious detection. In the same vein, Busch, Dürschmid, and Herrmann (2010) argue that their late positivity might reflect maintained focussed attention on the change as a prerequisite for consciousness.

ERP components found for change blindness trials

The results for differentiated processing under change blindness are rather sparse. It seems that the failure to detect the change is expressed in later positive components. Fernandez-Duque et al. (2003) found a posterior positive enhancement in the time interval 240-300 ms in change blind trials as compared to attentional search without a change. Thus they conclude that implicit perception of a change is reflected in this time range. In their study, Niedeggen et al. (2001) also found a posterior positivity in flicker cycles previous to a change detection answer. As stated above the authors argue that this positivity might reflect attention allocation to the change that leads to awareness. Although the time range in the Niedeggen et al. study is later (400/500-700 ms) both positive deflections might reflect implicit change representation and following attention allocation. The P3 component should thus be able to reflect awareness of a change and might also be modulated by implicit contextual updating (Matt, Leuthold, & Sommer, 1992).

As stated above implicit change detection can be measured with the priming paradigm where the implicit detection of a stimulus activates semantic networks and thus leads to enhanced processing of associated stimuli or in reaction to the repetition of the presented stimuli. The N4 component is often used in paradigms of implicit semantic priming or repetition priming (Brown & Hagoort, 1993; Kiefer, 2002; Schnyer, Allen, & Forster, 1997) and thereby is said to reflect memory processes (Warrington & Weiskrantz, 1970). The association of the N4 to memory processes is also meaningful for the change blindness paradigm. The presented studies using event related potentials to research visual search processes in this paradigm showed the role of attention for change detection. Nevertheless the question remains if visual representations of the original and modified scene are sustained and if one predominates the other as suggested by the overwriting or first impression hypothesis. The N4 component seems to be quite well prepared to study the explicit or implicit modulation in representation storage (Kiefer, 2002; Kiefer & Spitzer, 2000; Ruz, Madrid, Lupianez, & Tudela, 2003). Busch (2013) found evidence for preserved representations of pre- and post-change objects even under change blindness. In his study he presented participants with a change blindness task and a subsequent recognition task in which they had to decide which of two objects was present in the change blindness scenes. One of the recognition objects was old (either the pre- or post-change item) and the other was a new item. He found an ERP effect for old as compared to new items even under change blindness. It is therefore clear that representations were stored in visual memory even though they are not used for change detection (Busch, 2013). Thus, ERP components are able to provide additional information concerning underlying mechanisms of attention and memory in visual search.

Localisation of neural correlates of change detection

Studies that are interested in the location of areas involved in change detection found that category specific regions responsible for object perception in the ventral stream and attention related parietal regions of the dorsal pathways are crucial for visual awareness (D. M. Beck, Rees, Frith, & Lavie, 2001; Eimer & Mazza, 2005). Beck, Muggleton, Walsh, and Lavie (2006) tested if parietal cortex plays a causal role for change detection and found that the disruption of activity in this area through repetitive transcranial magnetic stimulation reduced change detection. Hence again in accordance with the theories on change blindness assuming attention to be crucial for successful visual search, the brain areas associated with change detection are said to relate to object perception and attention.

Semantic object/scene features in change blindness

Experiments researching the change blindness phenomenon often use a purely perceptual array of single stimuli (M. R. Beck & Levin, 2003; Becker et al., 2000; Cole & Liversedge, 2006; Koivisto & Revonsuo, 2003; Landman et al., 2003; Mitroff et al., 2004; Schankin & Wascher, 2008; Scholl, 2000). With these arrays interference from top-down guided search strategies can be controlled. Thus the exclusion of semantic, knowledge or learning related aspects from the search process helps the controllability of influencing factors.

What are these semantic, knowledge or learning related aspects? Semantic is defined as meaning (VandenBos, 2007) and refers to the link between a signifier (words, phrases, signs, etc.) and the associated concept. Knowledge can be defined as information about, awareness or understanding of specific topics, which is acquired by experience, or learning (VandenBos, 2007). Learning itself is defined as the process through which new information is acquired, extended or adjusted (VandenBos, 2007). Thus semantic, knowledge or learning related aspects have a strong relation to memory. Information that signifies a concept activates knowledge stored in memory that is acquired, extended or adjusted by learning. The concepts will be referred to as semantic information: information that is related to memory traces and can activate these traces. The activation or acquisition of knowledge or more general semantic information processing seems to be a general processing mechanism as is clear from experiments in areas like natural categorisation (Fabre-Thorpe, Delorme, Marlot, & Thorpe, 2001; Schyns & Oliva, 1999), schemas and scripts (Abbott, Black, & Smith, 1985; Alba & Hasher, 1983; Brewer & Nakamura, 1984), expertise (Bilalic, McLeod, & Gobet, 2010; Takahashi & Watanabe, 2008; Werner & Thies, 2000), implicit sequence learning (Baldwin & Kutas, 1997; Frensch, Lin, & Buchner, 1998; Goschke & Bolte, 2007) as well as visual search (Henderson, 2003). The processing and interpretation of perceptual information can be guided by knowledge or expertise as is reported by Bilalić, McLeod, and Gobet (2009) or Henderson (2003).

In their experiments Bilalić and colleagues found evidence for Gobet and Simon (1996) template theory that perceptual knowledge about stimuli (the semantic of the stimuli) is learned with repeated exposure and associated with the knowledge about adequate actions (Bilalic, McLeod, & Gobet, 2008; Bilalic et al., 2009, 2010). For example the change in a semantically relevant stimuli (a traffic light goes from green to red) is followed by adequate learned reaction in drivers (hitting the brakes). The mechanism underlying this effect is the activation of stored memory traces. These traces allocate attention to information compatible with the memory content thus strengthening the evidence for it and activating the appropriate action associated with the memory content (Bilalic et al., 2009). Expertise thus can also reduce change blindness if the semantic context can be used to guide attention due to experience with the context as shown by Werner and Thies (2000).

In their experiments Bilalić and colleagues furthermore found a kind of blindness arising through the activation of stored memory traces like schemata. The activation of schemata and associated actions can prevent the detection of alternative and (possibly) better solutions to certain situations thereby rendering the person blind for the alternative (Einstellungs (set) effect, Bilalic et al., 2008, 2010). These results are confirmed by change blindness experiments by Takahashi and Watanabe (2008) who showed eye movement to the spatial position of previously experienced changes and thereby heightened change blindness for the actual changes. Thus it is not surprising, that change blindness experiments using search displays including semantic information (for example real world scenes/photographs) show the relevance of semantic, knowledge or learning related information for visual search (Hollingworth & Henderson, 2000; Kelley, Chun, & Chua, 2003; Pringle, Irwin, Kramer, & Atchley, 2001; Rensink et al., 1997; Stirk & Underwood, 2007). Nevertheless semantic information have not been included in the change blindness research as much as might have been expected from the width of research on the role of semantic information for information processing in general (Abbott et al., 1985; Baldwin & Kutas, 1997; Ballard, Hayhoe, & Pelz, 1995; Bilalic et al., 2008, 2009; Brewer & Nakamura, 1984; Chun & Jiang, 1999; Fabre-Thorpe et al., 2001; Frensch et al., 1998; Goschke & Bolte, 2007; Henderson, 2003; Hollingworth & Henderson, 2000; Kelley et al., 2003; Rensink et al., 1997; Schankin & Wascher, 2008; Schyns & Oliva, 1999; Scott, Tanaka, Sheinberg, & Curran, 2008; Werner & Thies, 2000). The assumed role of semantic information on visual search is attention allocation through the activation of knowledge from memory or learning. The allocation of attention can be achieved by other means than semantic, knowledge or learning related information, one of which is cueing.

Cueing – the influence of induced attention allocation on visual search

It is clear from the theories and behavioural as well as neurobiological evidence that the interaction of attention and visual memory play crucial roles for visual search. Hence, induced attention allocation through cueing is one way to study this interaction and is used in the following experiments. Thus in the next section the current state of research on cueing will be reviewed.

Cueing can be effective at different levels of the visual search process (Cavanaugh & Wurtz, 2004; Landman et al., 2003; Posner, 1980; Shiu & Pashler, 1994). They can be presented prior to the search display (Schmidt, Vogel, Woodman, & Luck, 2002), embedded in (Scholl, 2000) or between displays (Landman et al., 2003), or after the search display (Sergent et al., 2013).

Influence of cues prior to the search display/s

Posner (1980) stated that cueing allocates attention to the cued stimulus/position and enhances processing resources for this stimulus/position. Shiu and Pashler (1994) on the other hand argue against signal enhancement and present evidence for a noise reduction mechanism that acts on the inhibition of distracters in decision processes. Therefore, it is controversial if the allocation of attention influences processing on the perceptual or decisional level. Störmer, McDonald, and Hillyard (2009) investigated this controversy with the phenomenon that participants report higher subjective contrast for cued stimuli. They used electrophysiological recordings to ascertain if this subjective contrast facilitation is due to perceptual processes or later interpretation at the decision level. The authors found evidence that attention enhances perception at early stages in information processing (within the first 100 ms) and conclude that cueing affects perceptual processing rather than later decision processes.

Influence of cues embedded in the display/s

Cues that are embedded in the display as opposed to presented prior or after the display are also able to allocate attention to the cued stimulus and therefore enhance performance in visual search (Cavanaugh & Wurtz, 2004; Scholl, 2000). In contrast to the presentation of cues prior to the display this form of induced attention allocation does not rely on memory processes. If the cue is presented prior to the search display the location of the cue has to be stored in order to be efficient on visual search. This is not necessary if the cue is embedded in the display. Therefore attention is exogenously captured inside the search process and facilitates performance (Scholl, 2000).

Influence of cues between search displays

The presentation of cues between search displays in a change blindness paradigm should not rely on attention but rather on visual memory processes (Landman et al., 2003). Participants do not know which location will be cued between pre- and post-change display and thus cannot allocate attention to a certain location but have to search the original display as in experiments without cueing. If the cue presented between displays is effective a comparison between the object on the cued location in the pre- and post-change scene has to be done. For this comparison to take place the pre-change scene has to be represented in visual memory. As Sperling (1960) showed the post-cueing made the retrieval of information from the iconic memory possible. Landman et al. (2003) showed a facilitating effect of cues between displays even with blank screens exceeding the storage time of iconic memory (blanks of 1200 to 1500 ms) therefore presenting evidence for the involvement of visual short- and or long-term memory in change blindness (Hollingworth, 2006).

Influence of cues presented after the search display/s

As shown above the post-cue can enable retrieval from visual memory stores (Landman et al., 2003; Sperling, 1960). Further evidence for the role of post-cueing comes from Sergent, Wyart, Babo-Rebelo, Cohen, Naccache, and Tallon-Baudry (2013). They reported that post-cueing could trigger conscious perception. Therefore the allocation of attention does not only facilitate perception but also the consciousness the percept receives. Most interestingly this effect operates even retrospectively. This retrospective aspect of attentional processes on perception is again indicative of the involvement of visual memory stores in cueing. Thus post-cueing can affect the retrieval of representations, the consciousness a stored percept receives or acts as a dispeller for the retrieval blockage from the post- on the pre-change representation assumed by Yang and Yeh (2009).

Cue types

From the evidence reviewed here, it is clear that for the cue to be effective it does not have to be explicit like it is when presented prior, between or after the search display but can also be implicit when embedded in the search display and not instructed (Scholl, 2000). Furthermore Scholl reviews the distinction between attentional selection based on to the endogenous control of attention or on the exogenous capture of attention by Jonides (1981). This distinction is closely related to explicit and implicit cue processing. Cues that lead to the endogenous control of attention are mainly instructed and explicitly represented. Cues that lead to the exogenous capture of attention are salient either perceptually (Schmidt et al., 2002; Scholl, 2000) or semantically (Hollingworth & Henderson, 2000; Rensink et al., 1997) and do not have to become explicit to allocate attention.

Cue validity

The validity of a cue indicates if the cue is drawing attention to the correct location (valid cue) or to an incorrect location (invalid cue) and influences detection performance (Posner, 1980). If the cue is valid performance is enhanced and detection is speeded. Invalid cues hinder visual search with the allocation of attention to a location where no target can be found. The difference between target detection times after validly and invalidly cues is the validity effect and reflects the time cost of disengaging attention from an invalidly cued position to the correct target position (Vossel, Thiel, & Fink, 2006).

Influence of cueing on attention and visual memory in change blindness

Schmidt, Vogel, Woodman, and Luck (2002) showed that the allocation of attention not only supports the encoding of visual information but also the storage of visual representations. Therefore cueing should be able to reduce change blindness through the attention allocation principle and the facilitation of visual representations. As stated above attention is crucial for the formation of coherent visual representations, which are necessary to detect changes across transients (Hollingworth, 2006; Rensink, 2000; Simons, 2000). In line with this assumption, change blindness studies were able to confirm facilitation of detection from cueing (Cavanaugh & Wurtz, 2004; Landman et al., 2003; Scholl, 2000). Studies researching the influence of cueing on change blindness used a wide variety of cues from perceptually salient colour singletons (Scholl, 2000), spatial location cues (Cavanaugh & Wurtz, 2004; Landman et al., 2003), late or sudden onset cues (Schmidt et al., 2002; Scholl, 2000), and even haptic cues referring to a certain location (Tan, Gray, Young, & Traylor, 2003). Therefore it is clear that cueing attenuated change blindness.

Questions of the presented dissertation

Although the body of literature on change blindness is quite big, perceptual low-level attributes are often used in the study of visual search (Cole & Liversedge, 2006; Scholl, 2000). Research of semantic, knowledge or learning related aspects of visual search are a bit sparser researched in the change blindness literature (Hollingworth & Henderson, 2000; Rensink et al., 1997; Stirk & Underwood, 2007). Thus the present experiments are designed to test how semantic attributes are processed in visual search and if they can allocate attention to reduce change blindness. The sequence of experiments is illustrated in table 1.

Table 1

Illustration of the experiments presented in this dissertation

experiment	**cue type**	**cue form**	**cue position**	**priming paradigm**	**stimulus material**
1	exogenous cue	lexical semantic	pre-change scene	semantic priming	letter matrices
	endogenous cue	perceptual cue	previous to the pre-change scene		
2	exogenous cue	lexical semantic	post-change scene		
	endogenous cue	perceptual cue	previous to the pre-change scene		
3	exogenous cue	semantic deviants	post-change scene	repetition priming	categorized line drawings
		perceptual deviants			
4		semantic deviants	pre-change scene		
		perceptual deviants			
5		semantic contextual cue	both scenes		

The literature on change blindness does not reveal if the processing of high-level attributes (semantic or lexical material, categorisation, and learning) is an automatic or general principle of visual search. Therefore the first experiments (1 and 2) test if semantic lexical material is able to endogenously capture attention and hence is automatically processed. The following experiments (3 and 4) are designed to compare the influence of semantic and perceptual object features in their ability to endogenously capture attention and which feature predominates in its influence on visual search, respectively. The last experiment (5) tests if the semantic features of the scene are automatically encoded if they provide a learning possibility designed to reduce change blindness.

The present experiments furthermore strive to close another gap in the literature. Although many studies are concerned with the role of visual memory for change blindness, its dependence on attention allocation is not systematically researched. Thus all of the following experiments include an implicit or explicit recognition task to research the stability of pre- and post-change representations depending on the attention manipulation of the change blindness task.

Cueing in the following experiments.

The cues used in this dissertation vary from endogenous and exogenous to semantic and perceptual as well as categorical cues effective through implicit learning.

In the first two experiments the possibility of semantic exogenous cues are studied. Cues are termed exogenous in these experiments when participants are not instructed to attend to them and no allusion to their presence is made but they are nevertheless assumed to capture attention and thereby influence visual search. The processing characteristics of these exogenous cues are the focus of the first experiments (1 and 2). Namely, are exogenous cues processed in a change blindness experiment, do they influence visual search and how do they interact with endogenous cues. Cues are termed endogenous in these experiments when participants are instructed to attend to them and are therefore overtly task relevant and assumed to lead to controlled attention allocation that influences visual search.

The following experiments (3 and 4) are designed to explore which features of exogenous cues are processed predominately in visual search. Therefore the influence of perceptual and semantic deviants on change blindness is compared in a semantic categorical context.

The fifth experiment further examines the role of context for visual search. In this last experiment semantic categorical context itself is the exogenous cue for change detection. The context predicts change position in a combination of implicit serial learning and the change blindness paradigm.

What is the role of categorisation/context for visual search?

A principle of visual search is information reduction through chunking or grouping of bottom-up information (Bilalic et al., 2009; Henderson, 2003; Simon, 1974) or categorisation and activation of top-down knowledge (Bilalic et al., 2010; Fabre-Thorpe et al., 2001; Henderson, 2003; Takahashi & Watanabe, 2008; Werner & Thies, 2000). Categorisation seems to be a general principle of information processing and reduction (Fabre-Thorpe et al., 2001). Fabre-Thorpe, Delorme, Marlot, and Thorpe (2001) showed evidence that categorization is achieved within the first 150 ms after stimulus presentation for a wide variety of categories. This time limit could not be modulated by experience and the authors thus assumed that categorisation is a general mechanism of information processing. The speed of categorisation is also reproduced in studies using electrophysiological or functional magnet resonance imaging (Antal et al., 2001; Antal, Szabolcs, Kovacs, Janka, & Benedek, 2000). Schyns and Oliva (1999) furthermore showed that categorisation is completed and modulates perception processes before these are concluded. The categorisation of scene elements into a coherent semantic context likewise influences visual search (Hollingworth & Henderson, 2000). Hence it is likely that categorisation is an important mechanism in visual search. Nevertheless this mechanism is in most change blindness studies not explicitly addressed. Categorisation is evident for example when real world scenes are used in change blindness studies but only a very small number of studies include categories/context as an experimental variable (Hollingworth & Henderson, 2000; Stirk & Underwood, 2007). Categorisation and/or the context of a scene are clearly high-level semantic attributes that are constantly used to guide perception and memory in every-day life (Abbott et al., 1985; Alba & Hasher, 1983; Gobet et al., 2001; Henderson, 2003; Schank & Abelson, 1977) and are thus included in the following experiments.

Categorisation/context in the following experiments.

In experiment three and four the stimuli in the change blindness displays can be categorised. The exogenous cue constitutes either a semantic deviant to the category or a perceptual deviant to the pre-change object. The categorisation of the stimuli should be quite fast and influence change detection for the semantic deviants according to Hollingworth and Henderson (2000).

The fifth experiment uses categories as predictors for change location. Thus, for successful detection objects have to be categorised and the relation of category and change position has to be encoded. If categorisation is such a general mechanism as the literature suggests this should be successful (Antal et al., 2001; Antal et al., 2000; Fabre-Thorpe et al., 2001).

Is there evidence for lexical semantic processing in visual search?

A related concept to information reduction as depicted in the previous section is automatic semantic processing. In the first two experiments a lexical semantic exogenous cue (prime word) is embedded in the search display (letter matrix). Although this word is not instructed or mentioned at all it is task relevant in two ways. First, semantic processing reduces the number of stimuli to be searched (see literature on chunking, Simon, 1974). Second, the word is changed between the displays into a non-word thereby rendering the detection of the semantic exogenous cue profitable for change detection. Nevertheless, the task is change detection and does not rely on lexical processing. Therefore, semantic processing in the first two experiments would be another sign for the importance of information reduction in visual search. To account for implicit semantic processing the effect is tested through semantic priming as is further detailed in the next but one section on the stability of visual representations.

Can the paradigm of implicit learning be used to influence visual search?

Alike to cueing implicit serial learning operates on the allocation of attention to positions (Nissen, Willingham, & Bullemer, 1987). In the implicit serial learning paradigm participants are presented with a serial presentation of stimuli that follow an inherent order. If this sequence is learned task performance is increased. This sequence might be explicitly represented or influence performance only on an implicit level (Frensch et al., 1998). Therefore it might be possible to adapt serial learning to the change blindness paradigm. Learning is another example for a high-level semantic process that might be used in visual search through the guidance of perception (Henderson, 2003) but is not studied in change blindness experiments.

In the fifth experiment implicit serial learning is combined with the change blindness paradigm. The objects presented in a scene can be categorised and this category predicts the change position. Therefore, if the predictive relation is learned attention should be allocated to the predicted positions. As stated above this attention allocation should facilitate visual storage of information at the predicted positions and therefore enhance change detection. Furthermore the predicted change positions should be stored as stable visual representations

(Schmidt et al., 2002). Again this is studied with repetition priming as detailed in the next section.

Are there sustained visual representations in visual search?

As illustrated above the stability of pre- and post-change representation is an open question. Many studies show an advantage for post-change representations (M. R. Beck & Levin, 2003; Busch, 2013). This might be due to retrieval blockage relying on the recency effect (Broadbent & Broadbent, 1981; Yeh & Yang, 2009). Undisputed is the role of attention for the formation of visual representations (Hollingworth, 2006; Schmidt et al., 2002).

Hence, the influence of semantic processing used in the following experiments on visual representations is researched. As shown above, Simons and Rensink (2005) argue that it is difficult to conclude on the formation of representations from change detection results (see also Busch, 2013). One method to study the content of visual memory is priming. With priming it is possible to provide evidence for sustained representations without conscious access necessary (Rensink, 2002).

In the priming paradigm a prime is presented followed by a target. The processing of the prime activates semantic networks through spreading activation or controlled semantic processing and promotes the pre-activation of associated concepts/words as well as holding the prime active. This facilitates the processing of following target words that are either a repetition of the prime (repetition priming) or are contained in these semantic networks (semantic priming) as compared to unrelated targets (Kiefer, Weisbrod, Kern, Maier, & Spitzer, 1998; Neely, 1977; Rugg, 1987). Thus priming is closely related to cueing. Cueing allocates attention to a certain stimulus/location and promotes its processing added by memory processes. Priming activates memory processes and thus promotes target processing. In the following experiments cueing is used to allocate attention and priming to see if the cued stimuli are able to form stable representations.

Priming in the following experiments.

In the first two experiments semantic priming is used to evaluate the influence of an exogenous embedded cue. Subsequent to the change blindness task an associated or not-associated target is presented. If the cue is able to exogenously capture attention it is assumed that the stability of visual representation is heightened by this attention allocation (Schmidt et al., 2002) and a priming effect should be evident for implicit and explicit cue processing (Neely, 1977, 1991).

In experiments 3 to 5 repetition priming is used to evaluate the stability of visual representations. Repetition priming should be the more enhanced the more attention is captured by the exogenous cue. Thus, the influence of exogenous semantic and perceptual cues on the stability of visual representations can be inferred in experiment 3 and 4 as well as the importance of the position of cues in the pre- or post-change scene for their respective representation. In the fifth experiment the influence of implicit learning on the stability of representations can be evaluated.

As reviewed above event related potentials are able to reveal insights into processes not possible with behavioural data. Therefore in all presented experiments electrophysiological data is recorded to further study the interaction of attention and visual memory in visual search.

As outlined above the following experiments strive to research the influence of semantic processing on attention and visual memory in the change blindness paradigm. Throughout the experiments the level of semantic processing increases from lexical processing of single words to categorisation of whole search displays to learning of predictive relations between categories and change positions.

General Methods

In the following sections the methods used in all presented experiments are described. Specifics of the individual experiments are explained in the method sections of the different experiments.

Participants

Participants were recruited from experimental courses and by advertising the experiments at Free University Berlin. They received either course credit or payment of between 10 and 20 Euro depending on the length of the experiment.

Execution period

The experiments were conducted between March 2009 and November 2011 in the laboratory track of the department for General Psychology/Neuropsychology of Prof. Dr. Michael Niedeggen. All rooms were equipped with sound absorbers and screened from electric artefacts. Lighting was shaded throughout the experiments.

Stimuli (Change Blindness)

The five experiments use the one-shot flicker paradigm. The one-shot flicker paradigm contains only two scenes: the original and modified scene (see figure 1). The scenes are presented once for 1000 ms each with a blank screen presented for 250 ms before a change detection decision is requested (change blindness task). The one-shot flicker paradigm enables one to evaluate the stability of the representation of the pre- and post-change scene. To achieve this end the original and modified scene are followed by a target word that refers to an item of the pre- or post-change scene or a new item not presented in the current trial. The target word is followed by a control task.

The experimental procedures of the individual experiments are explained in the respective method sections. The general structure of the experiments can be seen in figure 5.

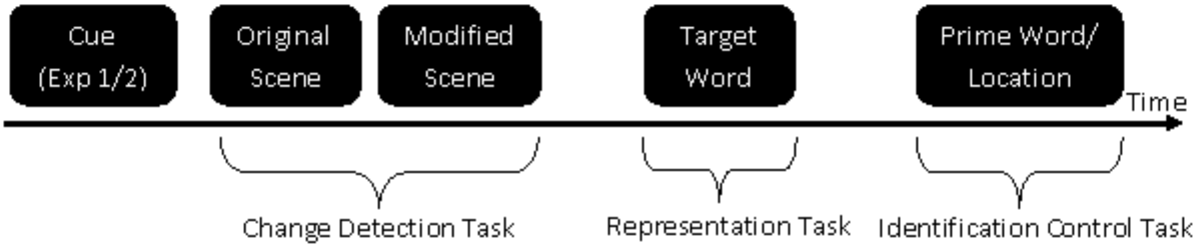


Figure 5. General procedure of the five experiments. In the first two experiments the change detection task is preceded by the perceptual cue. Participants had to decide if they detected a change via key press. After the target word presentation participants had to indicate by a key press if they encountered the corresponding item in the original or modified scenes in experiments 3 through five or just look at it in experiments 1 and 2. Finally the participants had to indicate were or what the change was.

Laboratory setting

The participants were seated in a distance of 150 cm from a 21’’ PC monitor. Stimuli were presented in black on a white background resulting in 97% contrast. The programs were created with and controlled by E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). Reactions were recorded from the E-Prime SRBox (Psychology Software Tools, Inc., Sharpsburg, PA) or a 10 key Response Box with the same software.

Procedure

Subjects were informed about the general structure of the experiment and the procedure they were to undergo (i. e. application of the EEG, conduction of the experiment, removal of the electrodes, debriefing). Following the electrode application, which took approximately 30 to 40 minutes, an instruction was presented on the screen. Participants had the chance to practice for some trials before the experiment was starting and EEG was recorded. Practice trials were presented again if the participants were unsure if they understood the task or if the experimenter doubted the understanding of the task. After the subjects concluded the experiment they were debriefed concerning the aim and logic of the experiment they participated in and the EEG electrodes were removed. The follow up (removal of the electrodes, debriefing) took ca. 20 to 30 minutes. Participants had the possibility to wash their hair in the laboratories facilities.

EEG data recording

In all experiments EEG data was acquired along with reaction times and detection rates. The active electrodes (in a varying number depending on the experiment) as well as the reference electrodes (linked mastoids) and the ground (Fcz) were applicated on the scalp with an electrode cap (EasyCap, Herrsching, Germany). The vertical EOG were placed above and under the left eye and horizontal EOG was placed on the temples. The scalp and EOG positions were prepared using Abralyte peeling crème (Abralyte 2000, EasyCap, Herrsching, Germany) and Isopropylalcohol (70%). Impedances for the reference were kept below 5 kΩ and for the remaining electrodes below 10 kΩ.

EEG was recorded continuously, sampled at 500 Hz, and online band pass-filtered (0.1 to 1000 Hz). The E-Prime program generated triggers. Offline, EEG data were segmented to epochs extending from -100 to 900 ms and aligned to the onset of the to-be analysed image/word. Each segment was filtered (0.3 - 30 Hz, -24 dB cut-offs), baseline corrected (-100 to 50 ms), and controlled for muscular or ocular artefacts. To prevent ocular artefacts the participants were instructed to fixate on a fixation cross located in the middle of the screen and refrain from blinking while the trial lasted.

Statistical analyses

To analyse the behavioural as well as the electrophysiological data repeated measures analysis of variance were used. To clarify interactions or compare effects t-tests were applied. If the comparison of effects over experiments was done this factor was included in the analyses of variance as a between subjects factor. EEG data was analysed using Brain Vision Analyzer (Version 1.05, Brain Products GmbH, Munich, Germany). Statistical analysis of EEG and behavioural data was done with PASW Statistics (IBM Corporation, Armonk, New York, USA). F-values were corrected according to Greenhouse-Geisser.

Experiment one and two

Processing characteristics of induced attention allocation

The first two experiments are designed to see if semantic stimuli are processed and are able to automatically capture attention as endogenous cues. Furthermore they should answer the question how this processing affects the stability of representations and interacts with controlled endogenous attention allocation. In the following section I will review research on the endogenous and exogenous allocation of attention through cues in visual search paradigms as well as the use of lexical semantic stimuli as those cues. Afterwards my research questions will be specified and hypothesis will be stated.

Cues may change the perception of visual scenes (Chun & Marois, 2002; Schmidt et al., 2002; Sperling, 1960). They capture attention either explicitly or implicitly and guide visual search through the allocation of attention as stated in the general introduction (Chun & Jiang, 1998; Posner, 1980). Scholl (2000) differentiates two types of attention allocation possible with cues. First, the endogenously control of attention allocation by cues that are often instructed and/or explicit. Second, the exogenously capture of attention by cues that are salient and can be implicit or explicit. These cueing effects will be described in detail.

Exogenous capture of attention

As stated above, cues that lead to the exogenous capture of attention have to have salient features that are able to focus attention on a stimulus or position without an instruction to do so or the necessity of explicit representation. Features that exogenously draw attention to a stimulus are manifold as the body of literature on automatic processing and cueing suggests (Neely, 1977; Schmidt et al., 2002; Stroop, 1935; Theeuwes, 1992). One line is the perceptual salience of the stimuli due to noticeable or rare/singular stimuli feature (Lien, Ruthruff, & Cornett, 2010) that might pop-out from the context (Wang, Cavanagh, & Green, 1994). Another line is semantic processing (Deacon & Shelley-Tremblay, 2000; Kiefer, 2002; Stroop, 1935). The experiments conducted by Stroop (1935) showed that semantic stimuli exogenously captured attention and interfered with the task at hand. Hollingworth and Henderson (2000) were able to show that change detection is higher for stimuli deviant to a semantic context. They assume that the semantic deviant captured attention and thus enhanced visual search. Rensink, O'Reagan, and Clark (1997) showed that change detection at positions of central interest in a scene is much better than detection at positions of marginal interest. Therefore it is clear that perceptual as well as semantic stimulus features are able to exogenously capture attention to a stimuli or position and hence can be used as cues. Cues that have features able to capture attention to a certain visual spatial position are termed exogenous cues in the following experiments.

Perceptual and semantic exogenous cues in visual search

In change blindness experiments participants normally do not know where to search for a change. This enhances the role of cues for the allocation of attention (Schmidt et al., 2002; Scholl, 2000). Change blindness is reduced by perceptual exogenous cues like colour singletons or sudden onset stimuli that capture attention and so cue the change object or location (Schmidt et al., 2002; Scholl, 2000). In contrast to perceptual exogenous cues, experiments using semantic exogenous cues are sparse (Hollingworth & Henderson, 2000; Kelley et al., 2003; Rensink et al., 1997; Stirk & Underwood, 2007). As stated above, a change of a stimulus from semantically congruent to a context to semantically incongruent to it enhanced change detection (Hollingworth & Henderson, 2000; Stirk & Underwood, 2007). Therefore semantic deviancy or mismatches can serve as a cue, and also allocate attention to a certain object or location and thus attenuate change blindness. Furthermore regions of high semantic salience or interest are capable of attentional capture thereby serving as exogenous cues to facilitate detection of changes in these regions (Kelley et al., 2003; Rensink et al., 1997).

Endogenous control of attention

Cues that lead to the endogenous control of attention are mostly instructed or need explicit processing to be efficient (Müller & Rabbitt, 1989; Schmidt et al., 2002; Scholl, 2000). These cues can also be semantic or perceptual and allocate attention to a spatial location (Logan, 1995). Many studies using the cueing paradigm use cues that lead to the endogenous control of attention (Landman et al., 2003; Sergent et al., 2013; Shiu & Pashler, 1994; Yeh & Yang, 2008, 2009). Cues that are instructed and/or overtly task relevant and having features able to endogenously allocate attention to a certain visual spatial position are termed endogenous cues in the following experiments.

Perceptual endogenous cues are often geometric forms at the location of the target/change (Landman et al., 2003; Shiu & Pashler, 1994), the colouring or brightening of place holders (Müller & Rabbitt, 1989; Sergent et al., 2013) or arrows pointing to this location (Cavanaugh & Wurtz, 2004; Müller & Rabbitt, 1989) and participants are instructed that the cues are predictive for the search task. Semantic endogenous cues used in visual search are for example lexical semantic direction cues (“up”, “down”, etc., see Hommel, Pratt, Colzato, & Godijn, 2001). The cues are mostly presented prior to the search display or changed scene (Besner, Risko, & Sklair, 2005; Cavanaugh & Wurtz, 2004; Hommel et al., 2001; Landman et al., 2003; Müller & Rabbitt, 1989) or following the display to retrieve visual representations from visual memory (Sergent et al., 2013). Endogenous cues control the allocation of attention because participants are instructed to do so (Besner et al., 2005; Cavanaugh & Wurtz, 2004; Hommel et al., 2001; Landman et al., 2003) or the cues have to be encoded to perform the task (Dell'Acqua, Pesciarelli, Jolicour, Eimer, & Peressotti, 2007;

a lexical decision task has to be done for green stimuli, thus the colour cue has to be encoded to perform the task). Endogenous cues are often used in the change blindness paradigm where they facilitate detection (Cavanaugh & Wurtz, 2004; Landman et al., 2003; Schmidt et al., 2002; Shiu & Pashler, 1994).

Interaction of endogenous and exogenous attention allocation

The literature on contingent attentional capture shows that the endogenous control of attention through the instructed task can inhibit the exogenous capture of attention by perceptually salient or singular stimuli (Lien et al., 2010; Lien, Ruthruff, Goodin, & Remington, 2008). Lien and colleagues showed that in a visual search paradigm exogenous cues were only able to capture attention when they were contingent with task demands. They cued participants with perceptual exogenous cues (colour singletons or sudden onset stimuli) that only captured attention if they shared the target feature (colour or orientation) participants were instructed to search for (Lien et al., 2010; Lien et al., 2008). Eimer, Kiss, Press, and Sauter (2009) furthermore showed that task irrelevant perceptual exogenous cues are inhibited and even delay target selection.

Müller and Rabbitt (1989) directly compared the influence of cues that lead to the endogenous control of attention and cues that lead to the exogenous capture of attention. They concluded from their experiments that the effects of these cue types are additive if they are compatible and subtractive if they are incompatible thereby assuming two separate attentional mechanisms that act on a limited capacity system of attention. According to their argumentation this implicates that the exogenous capture of attention is generally operative but can be modified by the amount of capacity required by the endogenous control of attention. According to the above presented theories of visual search in change blindness (Hollingworth, 2006; Rensink, 2000) attention is a necessary precondition for change detection. Müller and Rabbitt (1989) showed in their experiments that the limited capacity system of attention is modulated to a higher degree by top-down attentional control than by bottom-up capture of attention.

Lexical semantic cues

Lexical semantic cues can be used to endogenously control the allocation of attention as well as to exogenously capture attention (Besner et al., 2005; Dell'Acqua et al., 2007; Hommel et al., 2001). Hommel, Pratt, Colzato, and Godijn (2001) showed that direction words (“up”, “down”, “left”, etc.) although non predictive of target position oriented spatial attention to the named direction. Therefore lexical semantic cues can be used to endogenously allocate attention to a spatial position. Dell'Acqua, Pesciarelli, Jolicoeur, Eimer, and Peressotti (2007) were able to show that a lexical semantic cue itself can exogenously capture attention to its location. They presented their participants with two letter strings each on one side of a fixation cross. Participants were instructed to react to the letter string of a certain colour and decide if the string was a word or non-word. The distractor was always a word either related or unrelated to the target (if the target was a word). They showed that spatial attention is drawn to a word distractor that is semantically related to the target word. Besner, Risko, and Sklair (2005) reviewed theories on the relation between visual-spatial attention and visual word recognition. One line of theories states that spatial attention is the prerequisite for visual word recognition. The other line of theories assumes that visual word recognition is facilitated by spatial attention but does not rely on it. The authors tested the theories with a spatial (pre-) cue that should allocate attention endogenously to a certain location and a lexical semantic prime outside this location that might exogenously capture attention. They found that no exogenous or semantically driven capture of attention could be found for the prime if cue validity was high and concluded that spatial attention is a prerequisite for visual word recognition. Stolz and Stevanovski (2004) also found modulation by cue validity and concluded in a line of argumentation similar to

Müller and Rabbitt (1989) that lexical semantic stimuli exogenously capture attention but this attentional mechanism is modified by the more flexible endogenous control of attention sensitive to task demands. Therefore visual word recognition exogenously captures attention if resources are not otherwise employed by the endogenous control of attention.

To further explore the role of both attentional mechanisms on visual search the design depicted in figure 6 was implemented in a change blindness paradigm. This paradigm furthermore allows the integration of research on memory processes into the visual search and attention study. Therefore it is possible to explore the role of attention for visual memory as well as the role of memory for visual search and thus the interaction of attention and visual memory. None of the experiments researching lexical semantic cues used the change blindness paradigm and thus could not estimate the interaction between allocated attention by cues and memory processes for visual search.

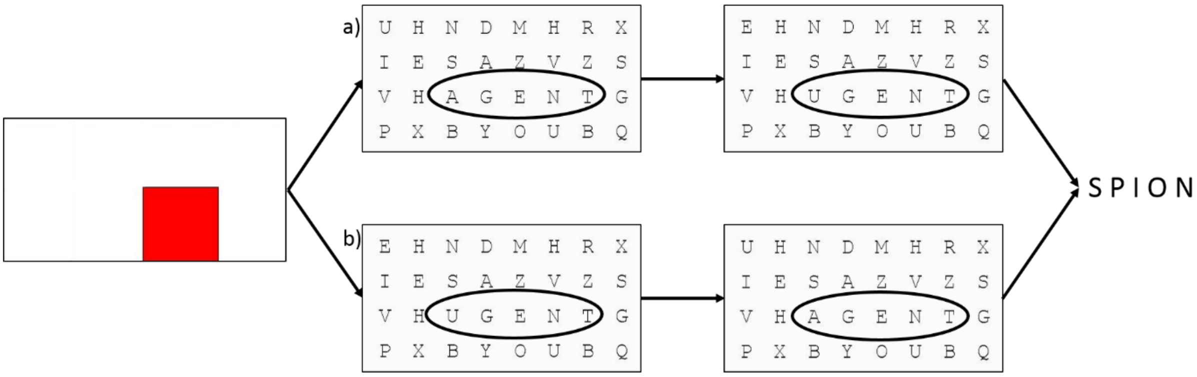


Figure 6. Experimental design depicting the perceptual endogenous cue presented prior to the change letter matrices. Embedded in the matrices is the exogenous lexical semantic cue that also serves as a prime. The exogenous cue can be presented a) in the pre- or b) in the post-change matrix. Following the change matrices is a target word associated or not associated to the prime.

Are exogenous lexical semantic cues able to attenuate change blindness?

As the studies on the exogenous capture of attention by words showed these lexical semantic stimuli are able to allocate attention to a certain spatial position (Besner et al., 2005; Dell'Acqua et al., 2007; Stolz & Stevanovski, 2004). Therefore they should attenuate change blindness if they cue the change location. In previous change blindness studies using semantic cues the facilitating effect relied on mismatch detection (Hollingworth & Henderson, 2000; Stirk & Underwood, 2007) or scene categorization (Kelley et al., 2003; Rensink et al., 1997). To test if spatial cueing through lexical semantic cues can reduce change blindness, a word was embedded in the change display of a one-shot flicker paradigm. The change displays consisted otherwise of single letters (figure 7). These stimuli were adopted from experiments done by Prof. Dr. Michael Niedeggen (Niedeggen, manuscript in preparation). The stimuli were designed to have a better insight into the representations formed from the pre- or post-change display. The classic approach to test this is to present the participants with a forced choice task including single stimuli. The answer to this task cannot answer if only single objects are represented in visual memory or if the whole scene is stored. The letter matrices however have to be represented in sufficient detail to allow priming to occur from the inherently presented prime word to the target word (Niedeggen, manuscript in preparation).

As shown repeatedly above, task demands (task set, relevance of features for the task, validity, etc.) influence the employment of the attentional mechanisms (Besner et al., 2005; Lien et al., 2010; Lien et al., 2008; Stolz & Stevanovski, 2004). Hence, the first question is: Is the facilitating effect of cueing on change detection dependent on the position of the exogenous cue? Task demands can be modulated in the change blindness paradigm by variation of cue position in the original or modified scene. The lexical semantic cue is embedded either in the pre- or post-change matrix. Exchanging one letter in the word to render it a non-word does the change. With this manipulation it is possible to vary the relevance of the exogenous cue for change detection. The exogenous cue embedded in the pre-change display captures attention and enhances the possibility for comparison of the stimuli at the attended position over the global transient (Hollingworth, 2006; Rensink, 2000). The exogenous cue embedded in the post-change matrix cues the location at which the change already took place. Therefore in this condition successful change detection depends on the sufficient representation of the pre-change display. Hence, the first question is:

Q 1: Is the facilitating effect of exogenous cueing on change detection seen in other studies (Hollingworth & Henderson, 2000; Kelley et al., 2003; Rensink et al., 1997) dependent on the position of the cue?

The facilitating effect of attentional allocation by cues is also reflected in the reaction times. Reaction times are speeded with the confidence participants have in their decision, which is presumed to be higher when attention is allocated to the change position (Eimer & Mazza, 2005; Kutas & Van Petten, 1994; Mitroff, Simons, & Franconeri, 2002). According to the literature on contingent attentional capture and attentional mechanisms underlying visual search and lexical processing (Besner et al., 2005; Lien et al., 2010; Lien et al., 2008; Stolz & Stevanovski, 2004) it can be hypothesized:

H1: If the word is embedded in the pre-change matrix, the allocation of attention to this lexical semantic cue should lead to heightened change detection and faster reaction times as compared to the word embedded in the post-change matrix.

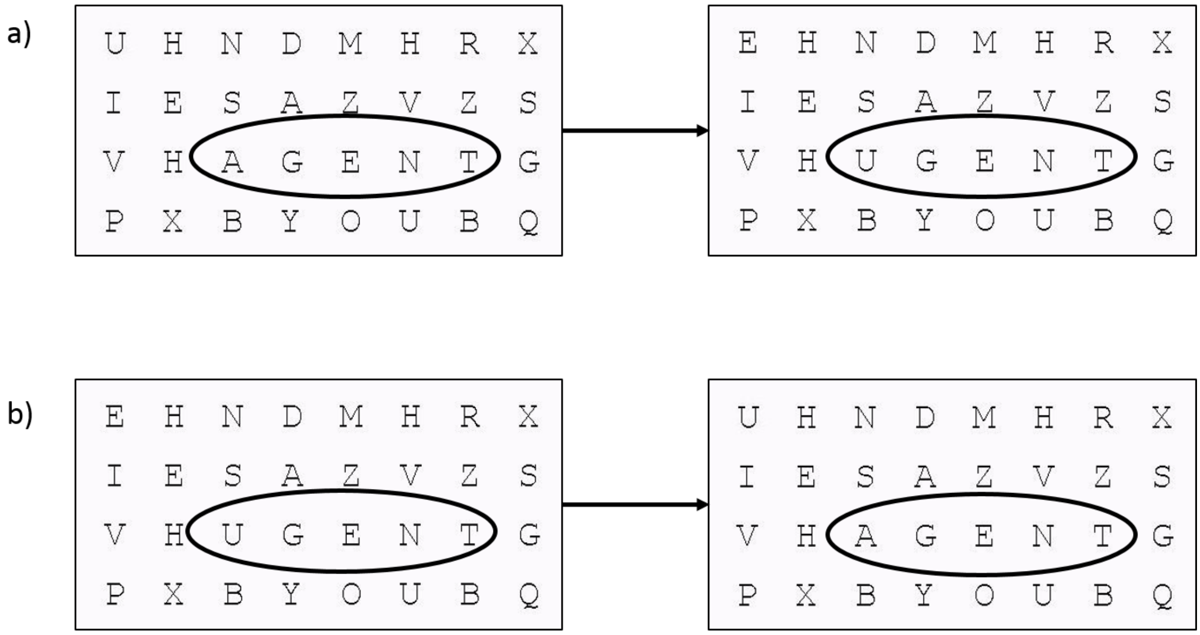


Figure 7. Change display of letter matrices. A) The lexical semantic exogenous cue is embedded in the pre-change matrix and the exchange of one letter renders it a non-word. B) The lexical semantic exogenous cue is embedded in the post-change matrix. The change of one letter of a non-word leads to the exogenous word cue.

Are exogenous lexical semantic cues able to form a stable visual representation?

As Schmidt et al. (2002) were able to show, cueing facilitates the stability of visual representations through the allocation of attention. This is the prerequisite for the formation of stable representations as stated by the reviewed theories (Hollingworth, 2006; Simons, 2000). Therefore it is reasonable to assume that this facilitating effect is also present for lexical semantic cues. As an indirect test for this hypothesis a semantic priming paradigm is added to the change blindness paradigm (see figure 8). After the one-shot flicker paradigm a target word is presented either associated or not associated to the lexical semantic cue. If the lexical semantic cue is processed a priming effect should be evident (Neely, 1977, 1991). The processing of the prime (lexical semantic cue) activates semantic networks through spreading activation or controlled semantic processing and promotes the pre-activation of associated concepts/words. This facilitates the processing of following target words contained in these semantic networks as compared to unrelated targets (Kiefer et al., 1998; Neely, 1977; Rugg, 1987). No task was posed to the target word to ensure that the prime word was foremost task relevant to the visual search task rather than for a lexical task. Therefore electrophysiological evidence was recorded to answer the posed question. According to the literature on semantic priming, a processed exogenous lexical semantic cue should elicit an enhanced N4 for not associated targets (Kutas & Van Petten, 1988). This effect is seen in a multitude of studies and reflects the activation of semantic networks by the prime that reduces processing resources used to analyse an associated target. Hence the second question is:

Q 2: Are exogenous lexical semantic cues able to form a stable representation expressed in a semantic priming effect?

According to the experiments by Schmidt et al. (2002) cueing leads to the formation of more stable visual representations. Therefore it can be hypothesized:

H 2a: Lexical semantic exogenous cues form stable representations that elicit a priming effect.

Again this could be dependent on the relevance of the cue for the change blindness task. The fact that the relevance of exogenous cue for task performance modulates the efficiency of the cue for attentional capture (Eimer et al., 2009; Lien et al., 2010; Lien et al., 2008) should also influence the formation of representation with more stable ones for more effective attention allocation (Hollingworth, 2006). It therefore can be further hypothesized:

H 2b: The priming effect is higher for cues embedded in the pre- than in the post-change matrix.

The exogenous capture of attention by the lexical semantic cue might lead to explicit word recognition. The explicit word recognition is used as a control condition or proof of concept for the facilitating effect of spatial attention allocation on change detection and representation formation.

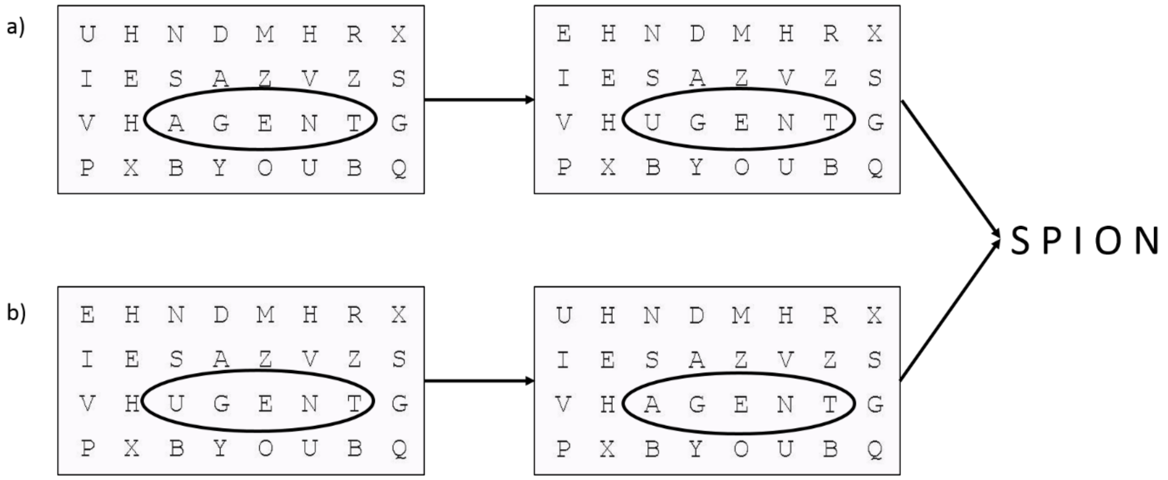


Figure 8. Embedded in the matrices is the exogenous lexical semantic cue that also serves as a prime. The exogenous cue can be presented a) in the pre- or b) in the post-change matrix. Following the change matrices is a target word associated or not associated to the prime.

How do endogenous and exogenous cues interact in their influence on change blindness?

Besner et al. (2005) showed in their experiments that the effect of exogenous cues is only evident in blocks where a prior endogenous cue has a low cue validity (50 %). They argued that endogenous cues are able to focus attention in highly valid cue conditions thereby leaving no resources in the limited capacity system for the exogenous cue to capture attention. In low cue validity conditions the endogenous cue is less relevant for task performance and thus lower resources are allocated to the top-down control of attention. This leaves resources for attentional capture by exogenous cues. Thus it can be hypothesized that an endogenous cue with a relative high validity hinders the processing of the exogenous cue. In the present experiments, a perceptual endogenous cue was presented prior to the change display in 60 % of the trials (see figure 9). The validity of this endogenous cue was relatively high (valid in two thirds of the trials). Thus the third question is:

Q 3: Are highly valid endogenous cue conditions able to allocate attentional resources to a degree that hinders attentional capture by the exogenous cue and its effect on change detection?

As Besner et al. (2005) were able to show, highly valid endogenous cue conditions hinder the processing of exogenous cues. Therefore in trials where an endogenous cue designed to allocation attention to one position and an exogenous cue designed to capture attention at another location the attention should be drawn to the position of the endogenous cue. Thus it can be hypothesized:

H 3: If the endogenous cue invalidly draws attention away from the change, change detection should be reduced as compared to trials without the endogenous cue where the exogenous cue can capture attention to the change location.

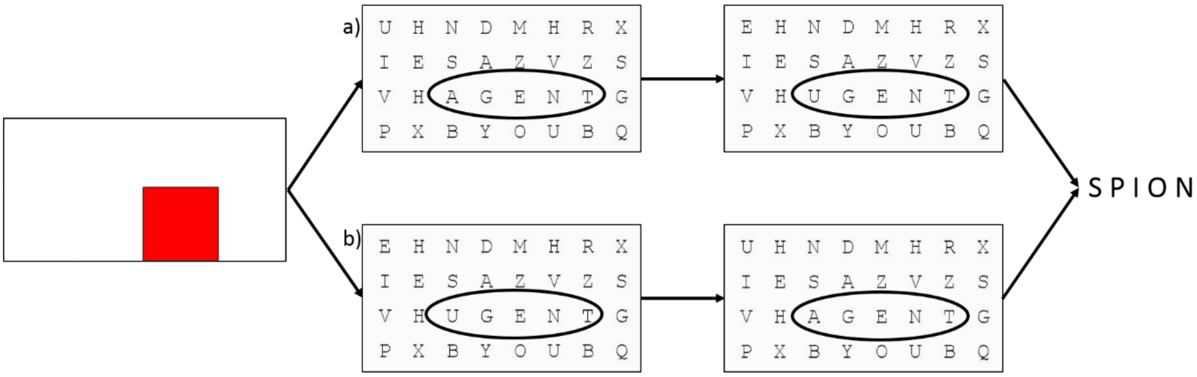


Figure 9. Experimental design depicting the perceptual endogenous cue presented prior to the change letter matrices. Embedded in the matrices is the exogenous lexical semantic cue that also serves as a prime. The exogenous cue can be presented a) in the pre- or b) in the post-change matrix. Following the change matrices is a target word associated or not associated to the prime.

How do endogenous and exogenous cues interact in their influence on the stability of visual representations?

If the endogenous cue does indeed draws attention away from the lexical semantic cue no stable visual representation should be formed (Besner et al., 2005; Stolz & Stevanovski, 2004). This should also be evident in the priming effect on the target word. Thus the fourth question is:

Q 4: Are highly valid endogenous cue conditions able to hinder the formation of stable visual representations of exogenous cues?

Besner et al. (2005) found that no repetition priming effect could be found for uncued prime words in their valid cue condition. It is therefore hypothesized:

H 4: No priming effect can be found for trials with invalid perceptual endogenous cues that should hinder the attentional capture by the exogenous cue.

Method and Material

Participants

Experiment 1 - EEG and behavioural data from 17 subjects were recorded. Seven participants had to be excluded in the analyses due to averages with a number of trials too small to analyse. This was due to too many artefacts in the EEG data and/or too many errors in the behavioural data. The analysed data set included 9 right-handed participants and one left-handed participant (9 female, 1 male; aged between 18 and 37; mean age: 23.9) with German mother tongue, and normal or corrected-to-normal vision.

Experiment 2 - EEG and behavioural data from 21 subjects were recorded. Two persons had to be excluded from the analyses due to averages with a number of trials too small to analyse. The analysed data set included 15 right-handed and 4 left-handed participants (9 female, 10 male; aged between 18 and 39; mean age: 24.4) with German mother tongue, and normal or corrected-to-normal vision.

Stimuli

At a viewing distance of 150 cm, the retinal size was 4.96° x 2.92° for each matrix as well as the cues. The target words were between four and seven letters long resulting in a range of retinal size from 1.5° x 0.27° to 2.7° x 0.27° and the prime words with five letters subtended 1.9° x 0.27°. Line drawings and words were printed in black and presented on a white background resulting in a contrast of 97%. The program was created using E-Prime 2.0 and used the E-Prime SRBox to record reactions (Psychology Software Tools, Inc., Sharpsburg, PA).

Pairs of 4*8 letter matrices were used, consisting of the 'original matrix' and 'changed matrix'. These matrices originated from a change blindness experiment conducted by Prof. Dr. Michael Niedeggen (Niedeggen, manuscript in preparation). They contained single letters that were obtained using a randomization procedure. The matrices were checked to avoid letter chains building words. Afterwards five letters were substituted with a German noun to obtain the 'original matrix'. The position of the noun within the matrix was counterbalanced (Niedeggen, manuscript in preparation). Two letters were then changed in the matrix to obtain the 'changed matrix'. One letter of the noun was exchanged to generate a non-word and one other letter in the matrix independent of the word (see figure 10). The single letter change was never done for an immediate neighbouring letter of the noun. 560 matrix pairs were constructed in this way.

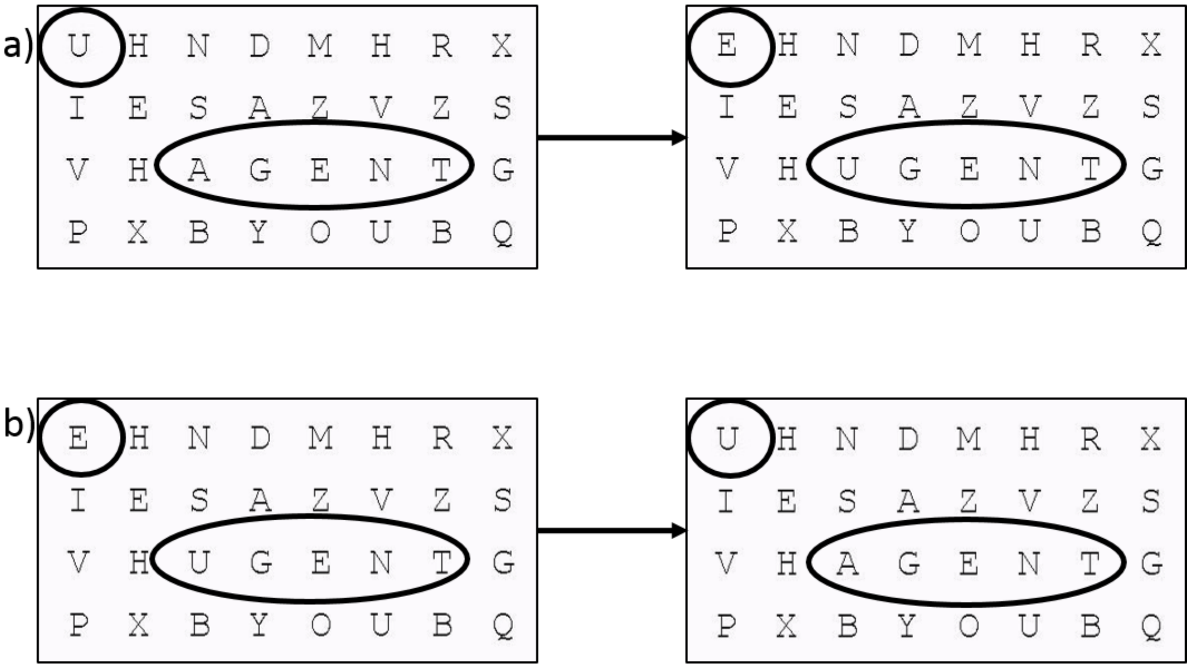


Figure 10. Matrix pairs depicting both the exchange of a single letter and the letter between word and non-word. The lexical semantic exogenous cue could be embedded a) in the pre- or b) in the post-change matrix.

For the purpose of studying exogenous and endogenous cues, an additional perceptual position cue (endogenous cue) preceded the original matrix. To research the stability of visual representation a target word succeeded it. The endogenous perceptual position cue varied in size and validity. It consisted of a frame the same size and position as the subsequent matrices and either an eighth or everything (i.e. no cue) coloured red.

To create the target words, two nouns were selected for every matrix word: one associated with the prime from the matrices (for example HURRICANE – STORM) and one not associated (HURRICANE – CHAIR).

Experimental design and procedure

Following the presentation of the cue (300 ms) a fixation cross was presented (300 ms) before the original and changed matrix were presented in a "one shot flicker paradigm". Both matrices were presented for 1000 ms interrupted by a blank screen for 250 ms.

Participants had to respond as quickly as possible either with a right or left key press when a change was detected. The time window for change detection spanned the presentation of the changed matrix and a 500 ms reaction time window directly following the changed matrix. Afterwards the target word was presented for 300 ms followed by a blank screen (1000 ms). At last the matrix word presented as long as the participants needed to decide if the presented word (prime word) was contained in the matrices (see figure 11).

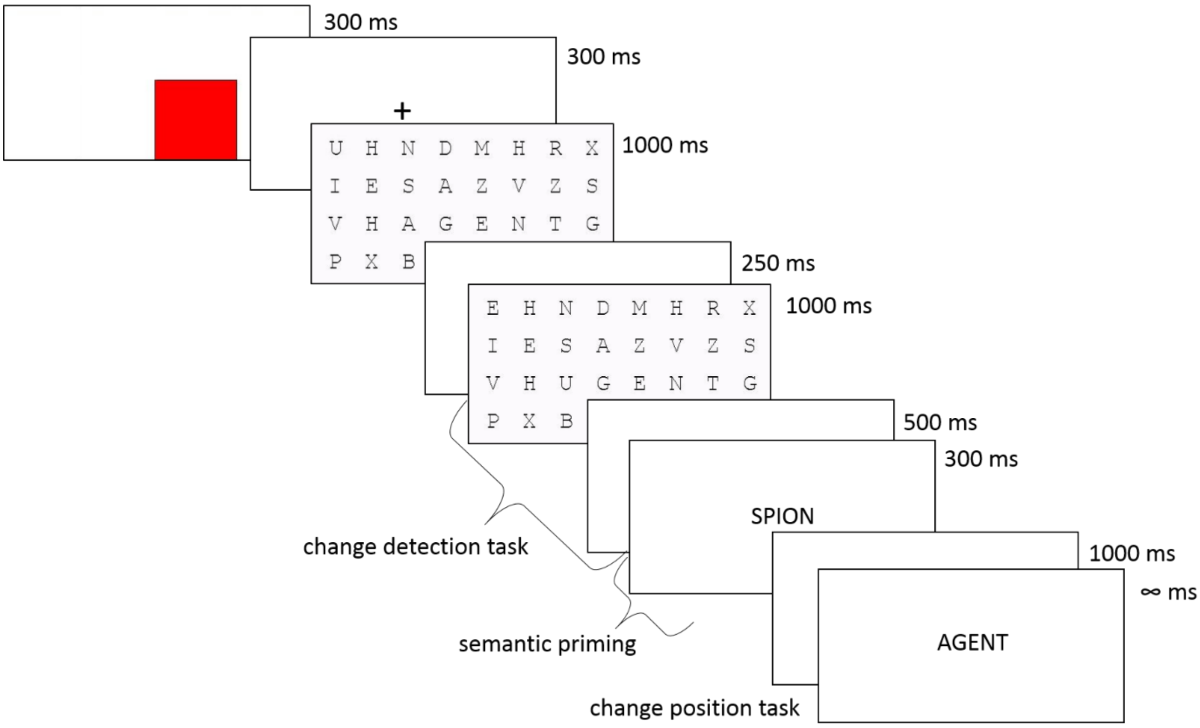


Figure 11. Participants were presented with a cue colouring either one eighth of the matrix or the full matrix frame. Two images - the original and modified matrix - were presented for 1,000 ms each, interrupted by a blank screen for 250 ms. The ‘flicker’ prevented the detection of a local object exchange. Participants had to indicate if they recognized the change with a key press. Afterwards the target word was presented for 300 ms followed by a blank of 1000 ms. At the end of the trial, subjects were to press a key if they saw the prime word in the matrices.

Trials were presented in 10 blocks. The first 200 trials were not endogenously cued (everything coloured) and the first four blocks thus each consisted of 50 trials of the no cue condition. In half of the trials in each no cue block the word was presented in the pre-change scene, and in the other half the word was presented in the post-change scene (figure 12).

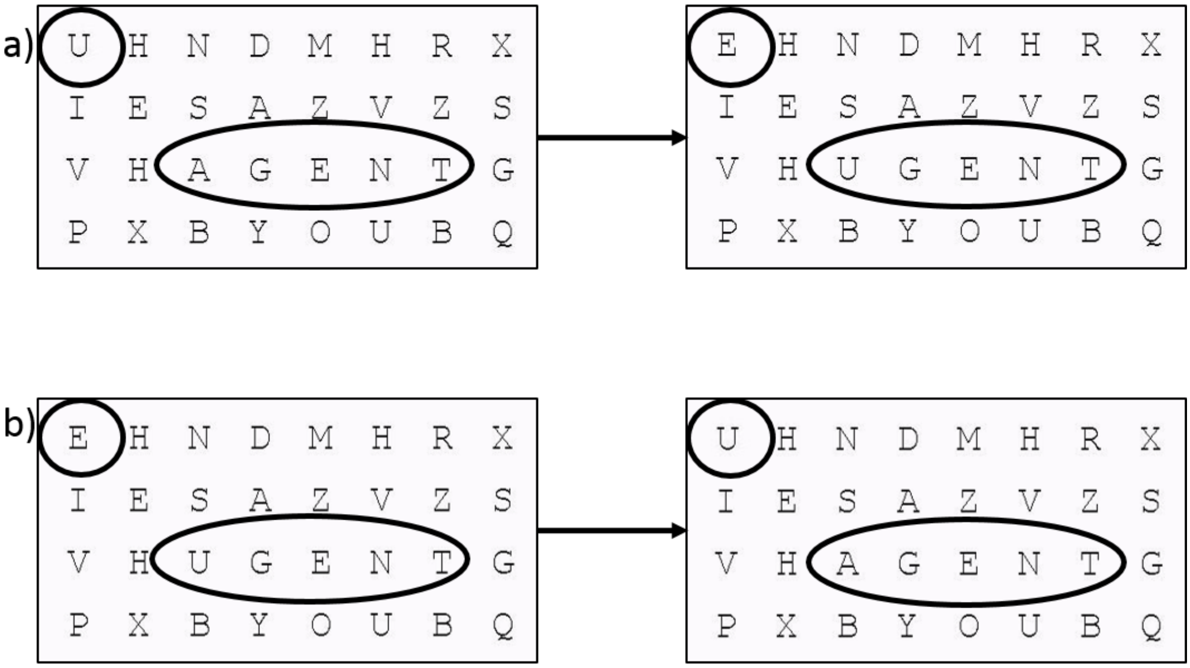


Figure 12. Sequence of change matrices dependent on the position of the lexical semantic exogenous cue a) in the pre-change matrix or b) in the post-change matrix.

The following 360 trials were cued ($^{1}/_{8}$ coloured). The endogenous cue validly showed the position of the change in two third of the trials. Half of the valid endogenous cues cued the position of the change in the word (word cue) and the other half the change outside the word (single letter cue). One third of the endogenous cues did not cue either change (invalid cue). The following six blocks each consisted of 60 trials 20 trials in each endogenous cue condition (valid word cue, valid single letter cue, invalid cue). In the first experiment the matrix word is always presented in the pre-change matrix in the last six blocks e.g. the blocks in which an additional endogenous cue is presented (figure 13).

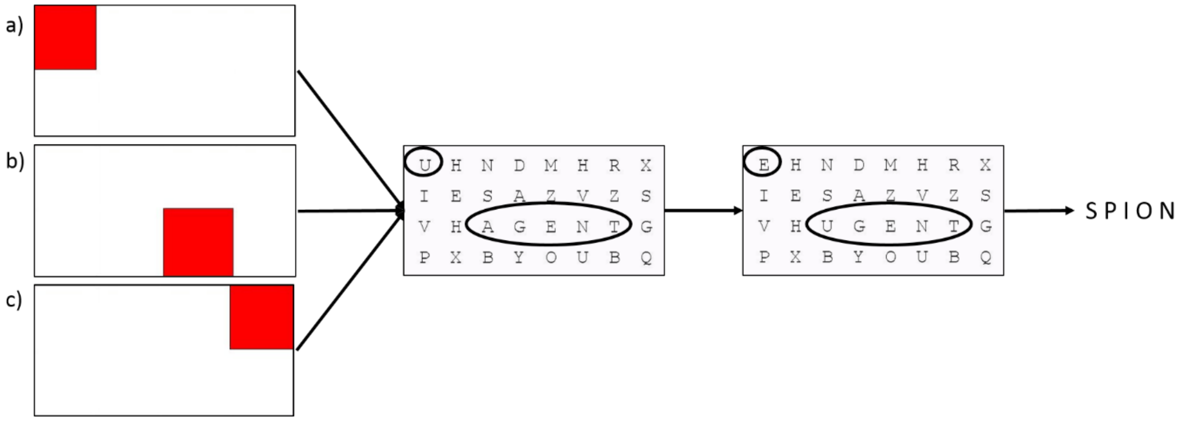


Figure 13. Cue conditions in the experimental design of blocks 5 to 10 in experiment one. The lexical semantic exogenous cue is always embedded in the pre-change matrix in these last blocks of the first experiment. A) The endogenous valid single letter cue, b) valid word cue, c) invalid cue.

The second experiment reverses this order in the last six blocks with the non-word presented in the pre-change matrix and the change reinstating the word in the post-change matrix (figure 14).

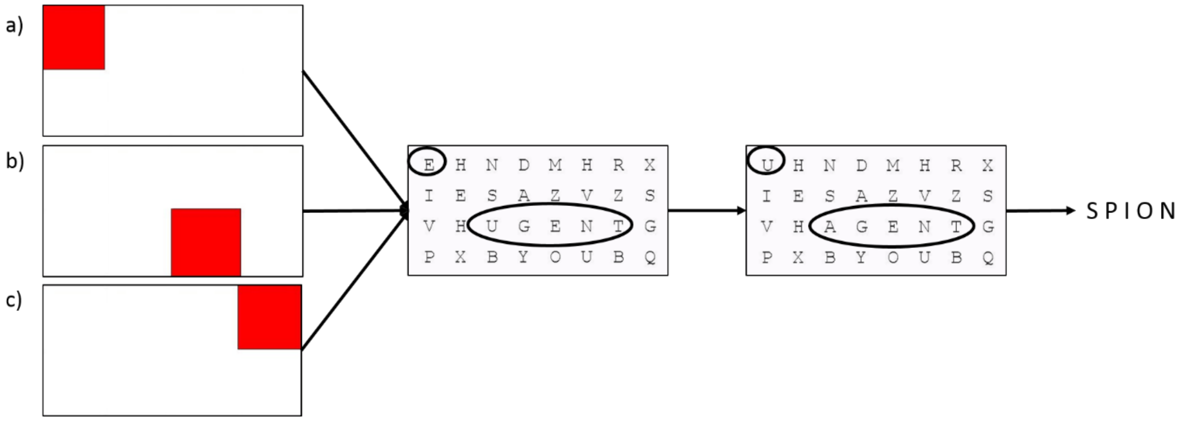


Figure 14. Cue conditions in the experimental design of blocks 5 to 10 in experiment two. The lexical semantic exogenous cue is always embedded in the post-change matrix in these last blocks of the second experiment. A) The endogenous valid single letter cue, b) valid word cue, c) invalid cue.

The execution of the experiments took approximately 90 minutes and therefore the whole space of time from the information about the procedure unto the debriefing was 140-160 minutes.

EEG data recording and analysis

EEG was recorded (BrainAmp Precision Products, 64 Channel amplifier, Brain Products, Munich, Germany) at 25 Ag/AgCl electrodes equidistantly positioned on the scalp and referenced to linked mastoids and electrode position Fcz as ground. Vertical and horizontal EOGs (vEOG, hEOG) were recorded to control for ocular artefacts.

For each participant and each electrode, artefact-free trials were averaged according to the pre- and post-change image, and the target. The pre- and post-change images were averaged according to the recognition of the prime word as indicated by the participants answer in the word recognition task (recognized vs. not recognized) and cue conditions (no cue – word in pre-change scene, no cue – word in post-change scene, invalid cue). The target images were averaged according to relation (associated vs. not-associated to the prime word), the recognition of the prime word, and the aforementioned cue conditions. To account for topographical differences, the factors caudality (frontal, central, parietal) and laterality (left, middle, right) were included in the analyses. Electrodes were assigned in the following matter to the topographical factors (1) frontal-left: F3, (2) frontal-middle: Fz, (3) frontal-right: F4, (4) central-left: C3, (5) central-middle: Cz, (6) central-right: C4, (7) parietal-left: P3, (8) parietal-middle: Pz, (9) parietal-right: P4. Electrode assignment was done according to the visual inspection of the grand averages. The analyses were focused on the N4 time interval (275-400/400-550 ms).

Experimental variables

On the electrophysiological level dependent variables were the ERP potentials in reaction to the onset of the pre- or post-change matrix and the onset of the target word. On the behavioural level dependent variables are the change detection rates for and the reaction times to the change matrix. The independent variables are different for the analyses done to answer the questions posed in the introduction.

Is the facilitating effect of exogenous cueing on change detection dependent on the position of the cue?

The behavioural analyses are separated according to explicit or implicit cue processing as indicated by the answer in the word recognition task. Change detection performance is further analysed according to the independent variable word position (in the pre- or post-change matrix) resulting in one-factorial repeated measurement designs. For these analyses the trials from the first four blocks of experiment one and two are jointly analysed. Both experiments were absolutely identical up to the end of the fourth block and can therefore be jointly analysed.

Are exogenous lexical semantic cues able to form a stable representation expressed in a semantic priming effect?

The electrophysiological analyses of the target word are also separated according to word recognition and analysed for the independent variables word position (pre-change vs. post-change scene), relation (associated vs. not associated), and caudality and laterality as described above resulting in four-factorial repeated measurement designs. The trials from the first four blocks of both experiments are again jointly analysed.

Are highly valid endogenous cue conditions able to hinder attentional capture by the exogenous cue and its effect on change detection?

The behavioural analyses are done separately for experiment one and two because in the six blocks with additional endogenous cueing the lexical semantic cue was embedded either in the pre-change matrix (experiment 1) or in the post-change matrix (experiment 2). Only implicit word processing is analysed to prevent the influence of explicit word processing to alter the relation between the endogenous control of attention according to the perceptual cue and the exogenous capture of attention by the lexical semantic cue. Independent variable in these one-factorial repeated measurement designs therefore is cue condition (no cue vs. invalid cue).

Are highly valid endogenous cue conditions able to hinder the formation of stable visual representations of exogenous cues?

The electrophysiological analyses of the target word are also separated by experiment and done for implicit word processing. Independent variables in each three-factorial repeated measurement design are cue condition (no cue vs. invalid cue), caudality, and laterality.

Results

Is the facilitating effect of exogenous cueing on change detection dependent on the position of the cue?

Behavioural Data:

As explained above recognized and not recognized words are separately analysed with the explicit word processing as a control condition for the possibility of attentional capture by lexical semantic stimuli in a visual search task.

Explicit prime processing.

Lexical semantic cues that are recognized raise change detection rates from 28.7 % for not-recognized words to 64.8 %. As shown in figure 15, change detection rates are much higher if the exogenous cue was embedded in the pre-change matrix and reaction times were faster. Correspondingly, the repeated measures analysis of variance (ANOVA) with the factor word position (pre- vs. post-change matrix) revealed a main effect of word position ($F(1, 28) = 54.06$, $p < 0.001$, $\eta_p^2 = 0.659$) with higher detection rates for word embedded in the pre-change matrix.

The ANOVA for reaction times of detected changes showed again a main effect of word position (F (1, 28) = 6.53, $p = 0.016$, $\eta_p^2 = 0.189$) with faster reaction times to detected changes if the exogenous cue was embedded in the pre-change matrix.

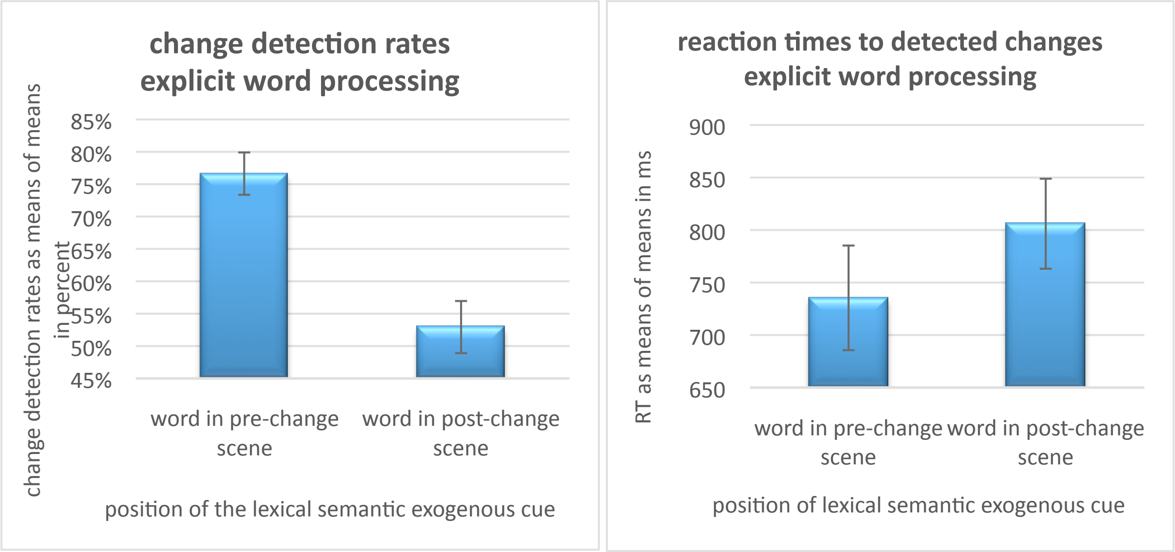


Figure 15. Left side: Change detection rates with recognized words (in percent) as a function of word position in the pre- or post-change scene with standard errors as error bars. Right side: Reaction times to detected changes and recognized words (in ms) as a function of word position in the pre- or post-change scene with standard errors as error bars.

Implicit prime processing.

Figure 16 shows that change detection rates do not differ in accordance to the position of the exogenous cue in the pre- or post-change matrix and may be slightly faster reaction times to detected change if the exogenous cues was embedded in the pre-change matrix. The repeated measures analysis of variance (ANOVA) with the factor word position unsurprisingly showed no effect of word position (F (1, 28) = 0.18, $p = 0.678$, $\eta_p^2 = 0.006$). The ANOVA for reaction times to detected changes also showed no effect of word position (F (1, 28) = 1.01, $p = 0.324$, $\eta_p^2 = 0.035$).

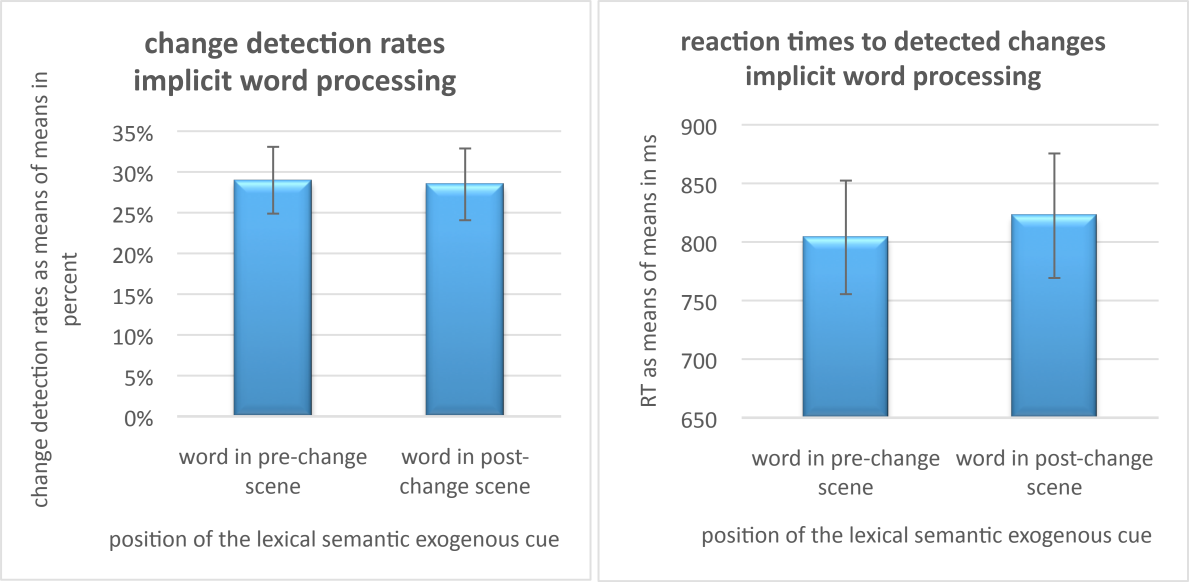


Figure 16. Left side: Change detection rates with not recognized words (in percent) as a function of word position in the pre- or post-change scene with standard errors as error bars. Right side: Reaction times to detected changes and not recognized words (in ms) as a function of word position in the pre- or post-change scene with standard errors as error bars.

Are exogenous lexical semantic cues able to form a stable representation expressed in a semantic priming effect?

ERP Data:

Following the predictions, the semantic processing of the word will also affect the processing of the upcoming target word. Since the explicit or implicit processing of the prime word will modulate the semantic priming effect on the target level, this factor will again be considered in the following analyses. The analyses are separated for explicit and implicit word processing with the recognized words as control condition or proof of concept.

Explicit word processing.

Inspection of the ERP waves lead to the selection of a reduced assignment of electrodes to the caudality and laterality positions (as named in the introduction to the present experiments) because the effect of semantic priming was more centrally distributed.

The grand averages for detected matrix words (figure 17) clearly show the expected results with an enhanced processing of not-associated words in the N4 time range (400-550 ms). The grand averages for not detected words show much less difference between associated and not associated words with an enhancement for the associated words (figure 18).

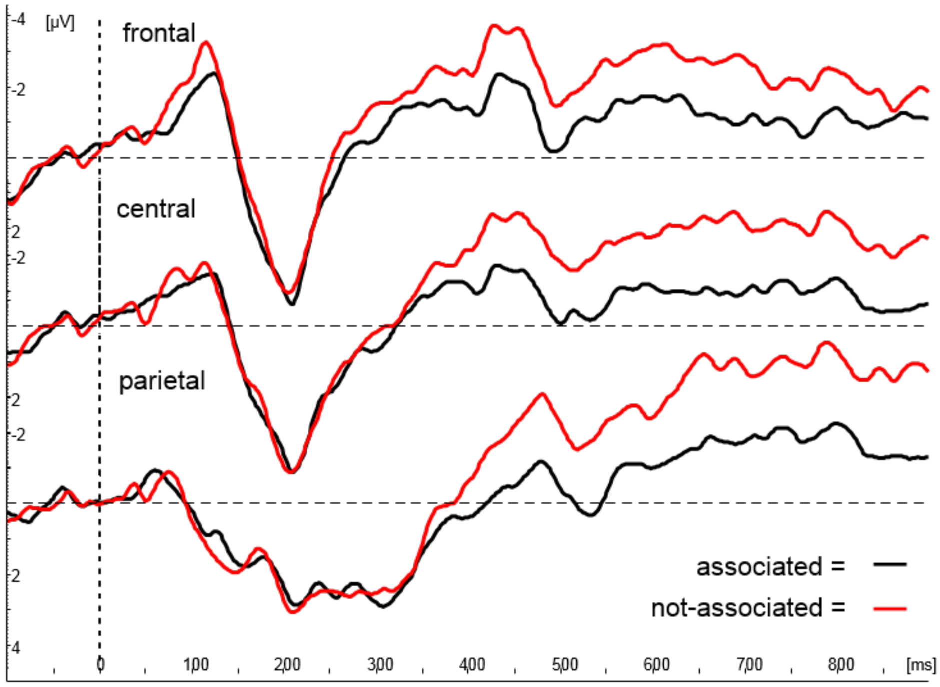


Figure 17. Grand averages for target words if the matrix word was detected at frontal (upper row), central (middle row), and parietal electrodes (lower row). Black lines are target words associated to the prime word in the matrix, red lines are not-associated target words.

The repeated measures ANOVA in the N4 time range for detected words with the factors relation (associated vs. not associated), word position (word in pre- vs. word in post-change scene), caudality (frontal, central, parietal), and laterality (left, middle, right) revealed a main effect of relation (F (1, 28) = 15.1, $p = 0.001$, $\eta_p^2 = 0.350$) as well as an interaction of caudality*laterality (F (4, 112) = 4.48, $p = 0.003$, $\eta_p^2 = 0.138$). The not-associated targets increased the N4 as was expected.

No further significant effects or interactions could be found for caudality (*F* (2, 56) = 1.78, $p = 0.191$, $\eta_p^2 = 0.060$), word position*caudality (*F* (2, 56) = 1.9, $p = 0.175$, $\eta_p^2 = 0.063$), word position*caudality*laterality (*F* (4, 112) = 2.22, $p = 0.090$, $\eta_p^2 = 0.073$), association*laterality (*F* (2, 56) = 3.41, $p = 0.053$, $\eta_p^2 = 0.109$), association*caudality*laterality (*F* (4, 112) = 1.88, $p = 0.135$, $\eta_p^2 = 0.063$), and word position*association*caudality*laterality (*F* (4, 112) = 2.34, $p = 0.078$, $\eta_p^2 = 0.077$) or any other effects (*F*s < 1).

Implicit word processing.

Grand averages revealed a shift of the time range affected by relation as well as a reversed priming effect. Semantically related words enhance the negativity in contrast to the explicit condition. Accordingly, the analyses for the not-detected matrix words did not show an effect in the N4 time range chosen for the recognized words (400-550) but a somehow earlier effect in the time interval 275-400 ms. In this time range the ANOVA with the factors relation, word position, caudality, and laterality a significant main effect of relation could be found (*F* (1, 28) = 5.02, $p = 0.033$, $\eta_p^2 = 0.152$) as well as a significant three-way interaction of relation*caudality*laterality (*F* (4, 112) = 3.31, $p = 0.037$, $\eta_p^2 = 0.106$) and main effects of caudality (*F* (2, 56) = 33.43, $p < 0.001$, $\eta_p^2 = 0.544$), laterality (*F* (2, 56) = 29.74, $p < 0.001$, $\eta_p^2 = 0.515$) and their interaction (*F* (4, 112) = 9.72, $p < 0.001$, $\eta_p^2 = 0.258$). The interaction of relation*caudality*laterality revealed a significantly more negative amplitude for associated as compared to not associated words especially at fronto-central (*t* (28) = -2.23, $p = 0.034$), frontal-right (*t* (28) = -2.68, $p = 0.012$), and central-right electrodes (*t* (28) = -2.15, $p = 0.040$).

No other significant effects or interactions could be found for word position (*F* (1, 28) = 2.48, $p = 0.126$, $\eta_p^2 = 0.081$), word position*caudality (*F* (2, 56) = 1.54, $p = 0.228$, $\eta_p^2 = 0.052$), association*caudality (*F* (2, 56) = 1.94, $p = 0.172$, $\eta_p^2 = 0.065$), and word position*association*caudality (F (2, 56) = 3.28, p = 0.062, η_p^2 = 0.102) or any other interaction (Fs < 1).

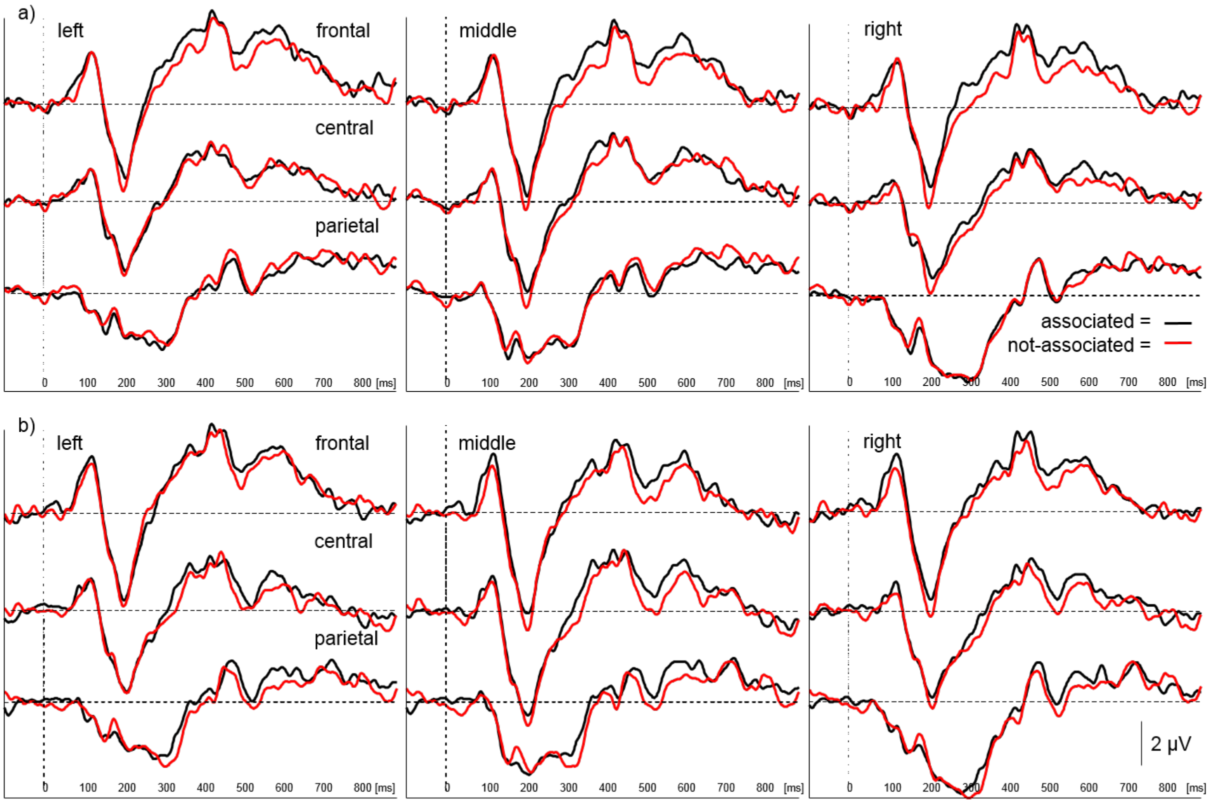


Figure 18. a) Grand averages for target words if the matrix word – presented in the *pre-change scene* - was not detected at caudal (frontal-upper rows, central-middle rows, parietal-lower rows) and lateral electrode positions (left-left panel, middle-middle panel, right-right panel). b) Grand averages for target words if the matrix word – presented in the *post-change scene* - was not detected at caudal (frontal-upper rows, central-middle rows, parietal-lower rows) and lateral electrode positions (left-left panel, middle-middle panel, right-right panel). Black lines are target words associated to the prime word in the matrix, red lines are not-associated target words.

Are highly valid endogenous cue conditions able to hinder attentional capture by the exogenous cue and its effect on change detection?

Behavioural Data:

The no cue condition (undisturbed by perceptual cues) is compared to the invalid cue condition to see if word recognition is reduced. As explained above this comparison is done for experiment one and two separately due to the position of the exogenous lexical semantic cue either in the pre-change matrix (experiment 1) or post-change matrix (experiment 2) in the blocks with additional endogenous perceptual cues. Word recognition decreases when an invalid cue draws the attention away from the semantic cue in experiment 1 (t (9) = 2.92, p = 0.017) as well as in experiment 2 (t (18) = 2.27, p = 0.036) although word detection is still present (figure 19).

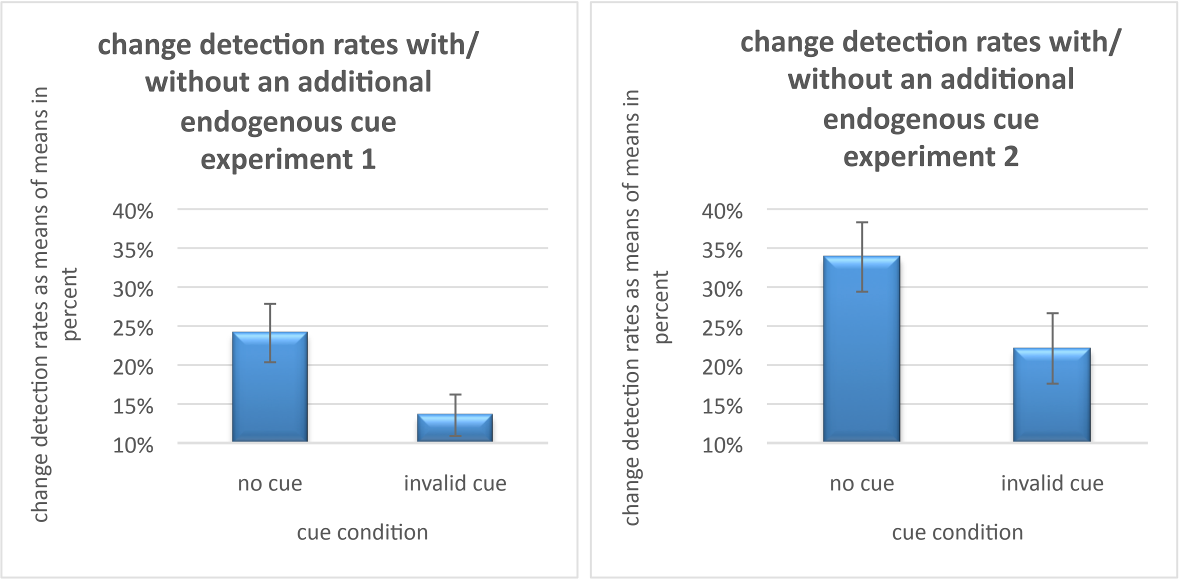


Figure 19. Left side: Change detection rates with not recognized words (in percent) as a function of an additional endogenous perceptual cue in experiment one (exogenous cue in the pre-change matrix) with standard errors as error bars. Right side: Change detection rates with not recognized words (in percent) as a function of an additional endogenous perceptual cue in experiment two (exogenous cue in the post-change matrix) with standard errors as error bars.

Are highly valid endogenous cue conditions able to hinder the formation of stable visual representations of exogenous cues?

ERP Data:

To answer this question the reaction to the target word is analysed for the no cue and the invalid cue conditions in the first and second experiment. Only the trials without matrix word detection were analysed to exclude the influence of explicit word processing. Therefore the 275-400 ms time interval found to be modulated by implicit prime word processing is analysed. As was done with the behavioural data, the electrophysiological data are again separately analysed for experiment one and two. In the blocks with prior endogenous cues the exogenous cue is always embedded in the pre- (experiment 1) or post-change matrix (experiment two). This makes it necessary to analyse the experiments separately. The number of participants differs between experiment one and two. To test if the significant effect found in the analyses for not-detected words above is due to significant effects in both experiments, experiment (1 vs. 2) was included in the ANOVA as between-subject factor. No interaction with this factor could be found (Fs < 1) and therefore the experiments could be analysed separately for the cueing effect.

Visual inspection of the grand averages showed that the endogenous perceptual cue influenced processing of the word in the 275-400 ms time range (figures 20 and 21). For reasons of clarity the ERP waves are averaged over associated and not-associated target words according to the following ANOVAS that revealed no effect or interaction of the relation factor with any of the other factors.

In the first experiment, the repeated measures ANOVA for the time interval (275-400 ms) with the factors cue condition (no cue vs. invalid cue), relation (associated vs. not-associated), caudality, and laterality showed a three-way interaction cue condition *caudality*laterality (F (4, 36) = 3.92, $p = 0.031$, $\eta_p^2 = 0.303$) as well as main effects of caudality (F (2, 18) = 16.47, $p = 0.002$, $\eta_p^2 = 0.647$) and laterality (F (2, 18) = 6.4, $p = 0.012$, $\eta_p^2 = 0.415$) and their interaction (F (4, 36) = 5.93, $p = 0.007$, $\eta_p^2 = 0.397$). The three-way interaction revealed a significant positive increase at parieto-central electrodes for the invalid cue condition (*t* (9) = -2.3, $p = 0.047$). No further significant effects or interactions could be found for cue condition*caudality (*F* (2, 18) = 1.78, $p = 0.214$, $\eta_p^2 = 0.165$), cue condition*laterality (*F* (2, 18) = 3.04, $p = 0.084$, $\eta_p^2 = 0.252$), relation*caudality (*F* (2, 18) = 4.52, $p = 0.058$, $\eta_p^2 = 0.334$), relation*caudality*laterality (*F* (4, 36) = 1.02, $p = 0.387$, $\eta_p^2 = 0.101$), cue condition*relation*caudality (*F* (2, 18) = 2.18, $p = 0.168$, $\eta_p^2 = 0.195$), cue condition*relation*caudality*laterality (*F* (4, 36) = 1.1, $p = 0.368$, $\eta_p^2 = 0.109$) or any other effects or interactions (*F*s < 1).

The analyses for the time interval (275-400 ms) in the second experiment revealed an interaction of cue condition*caudality (*F* (2, 36) = 4.42, $p = 0.041$, $\eta_p^2 = 0.197$) and a three-way interaction cue condition*caudality*laterality (*F* (4, 72) = 4.0, $p = 0.034$, $\eta_p^2 = 0.182$) as well as main effects of caudality (*F* (2, 36) = 26.49, $p < 0.001$, $\eta_p^2 = 0.595$), laterality (*F* (2, 36) = 16.36, $p < 0.001$, $\eta_p^2 = 0.476$) and their interaction (*F* (4, 72) = 4.33, $p = 0.026$, $\eta_p^2 = 0.194$). The invalid cues enhanced the negativity at fronto-central (*t* (18) = 2.55, $p = 0.020$) and frontal-right electrodes (*t* (18) = 2.84, $p = 0.011$).

No other significant effects or interactions could be found for cue condition*laterality (*F* (2, 36) = 3.71, $p = 0.051$, $\eta_p^2 = 0.171$), relation*laterality (*F* (2, 36) = 1.05, $p = 0.334$, $\eta_p^2 = 0.055$), relation*caudality*laterality (*F* (4, 72) = 1.13, $p = 0.326$, $\eta_p^2 = 0.059$) or any other effects or interactions (*F*s < 1).

Figure 20. Grand averages for the waves averaged over associated and not-associated target words in the no cue and invalid cue condition for *experiment 1* (exogenous lexical semantic cue in the pre-change matrix). Left side: Frontal (upper row), central (middle row), and parietal (lower row) electrodes. Right side: Left (upper row), middle (middle row), and right (lower row) electrodes. Black lines are reactions to the invalid cue; red lines are the reactions to the no cue condition.

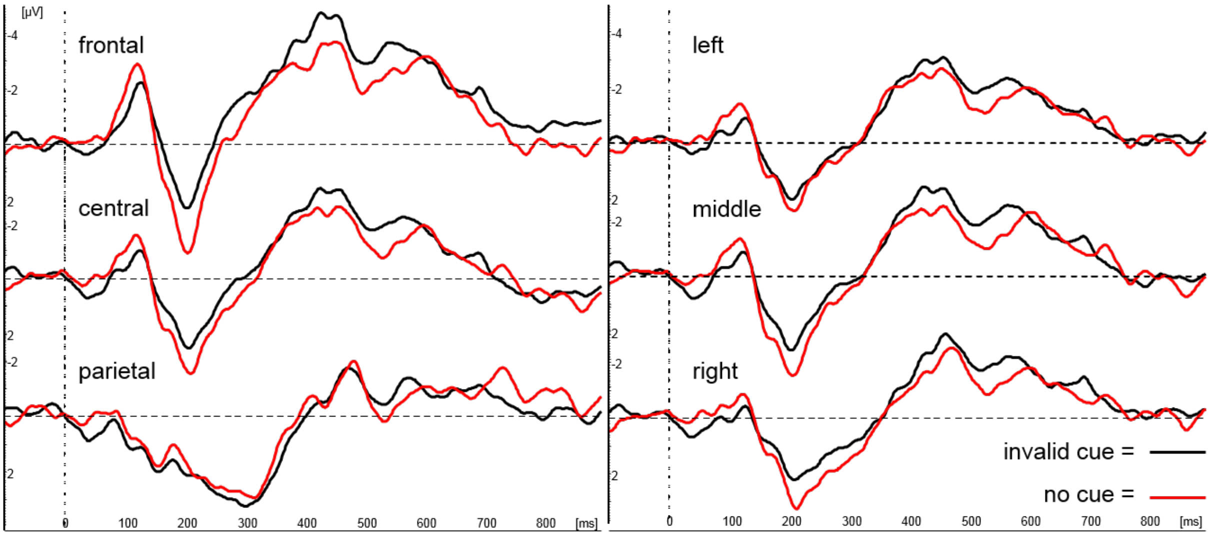


Figure 21. Grand averages for the waves averaged over associated and not-associated target words in the no cue and invalid cue condition for *experiment 2* (exogenous lexical semantic cue in the pre-change matrix). Left side: Frontal (upper row), central (middle row),

and parietal (lower row) electrodes. Right side: Left (upper row), middle (middle row), and right (lower row) electrodes. Black lines are reactions to the invalid cue; red lines are the reactions to the no cue condition.

Discussion

Summary

The exogenous lexical semantic cue embedded in the word matrices was clearly processed on the explicit and implicit level. Explicitly processed endogenous cues facilitated change detection and speeded reaction times especially if the cue was positioned in the pre-change matrix. Explicitly processed exogenous cues also primed the target word that showed a clear N4 increase for not-associated words. Implicitly processed endogenous words were not able to facilitate change detection or speed reaction times and did not vary with cue position. Nevertheless, they led to the formation of stable visual representations as reflected in a priming effect on the target word expressed in an increased frontal right negativity for associated words in the 275-400 ms time range.

The influence of the endogenous perceptual cue on the processing of the exogenous lexical semantic cue can be inferred from the reduction of change detection if an invalid cue hindered the processing of the valid exogenous cue. This is also mirrored in an increased P3 amplitude or an enhanced negativity in the 275-400 ms time range for the target word in experiment 1 and 2, respectively.

The influence of the exogenous lexical semantic cue on change blindness - behavioural data

The exogenous lexical semantic cue influenced change detection performance (detection rates and reaction times) depending on mode of processing. Words that were recognized and therefore explicitly processed enhanced change detection in comparison to implicitly processed ones (indicated by the failure to recognize these words). Furthermore the facilitating effect of explicitly processed exogenous cues did depend on task relevance of the cue. If the lexical semantic cue was embedded in the pre-change matrix the enhancement of change detection was much higher than if the cue was embedded in the post-change matrix. The same is true for the reaction times to detected changes. An exogenous cue embedded in the pre-change matrix should capture attention to the location of the cue and the content of this spatial location could be visually represented. This focusing of attention and subsequent visual representation should enhance change detection when the modified display is presented with the change at the attended location. The attentional capture to the change position furthermore enhances the confidence in the detection decision and thus leads to faster reaction times to detected changes (Eimer & Mazza, 2005; Kutas & Van Petten, 1994). If the exogenous cue is presented after the change took already place it might help to retrieve the information of the previous content at the cued location from visual memory stores (Sergent et al., 2013). This however is only possible if the change location was attended to and is sufficiently represented. Hence, the relevance of the exogenous cue for change detection is higher if it is presented in the pre-change matrix. This effect can be clearly seen in the change detection rates and reaction times of explicitly processed exogenous cues. However, this effect is missing for implicitly processed exogenous cues. This might lead to the conclusion that implicitly processed lexical semantic exogenous cues do not attenuate change blindness. This conclusion is further supported by the small change detection rates for not recognized exogenous cues (28.7%). But does it also lead to the conclusion that implicitly processed exogenous cues do not capture attention? If implicitly processed exogenous cues nevertheless captured attention this might have led to the formation of stable visual representations as stated by Schmidt et al. (2002).

The formation of stable visual representations due to exogenous lexical semantic cues

The exogenous cue is processed explicitly and implicitly in the matrices and contributes to the formation of stable visual representations. If the prime word is detected a clear N4 effect can be seen for the target word with an increased amplitude for not-associated words in the time interval 400-550 ms. If the prime word is not detected an implicit priming effect can be seen in the 275-400 ms time range with a higher amplitude for associated words. Nobre and McCarthy (1994) argue that the N400 component consists of numerous overlapping components and Dien, Frishkoff, Cerbone, and Tucker (2003) state that the N3 might be the earliest component in this conglomerate reflecting post-lexical processing of semantic information with sensitivity to semantic congruency. Neville, Kutas, Chesney, and Schmidt (1986) as well as Nobre and McCarthy (1994) found that the N3 reacts with higher amplitudes to congruent semantic stimuli. It therefore seems that a N3 effect is present in the first two experiments in the implicit priming condition. Significantly more negative amplitude for associated words was found in the 275-400 ms time interval especially at fronto-central and central-right electrodes. Therefore it is clear that the exogenous lexical semantic cue embedded in the matrices is processed and influences following stimuli irrespective of explicit detection.

It is unusual that the activation is right sided at central electrodes given the fact, that language processing is left lateralized in most studies (Neville et al., 1986; Nobre & Mccarthy, 1994; Ruz et al., 2003). The right hemispheric activation in the processing of the target word might be due to the fact that no task is related to the target word. Kiefer, Weisbrod, Kern, Maier, and Spitzer (1998) showed that left-hemispheric activation corresponded to behavioural semantic priming effects whereas no such correspondence could be found with right-hemispheric activation. Therefore the lack of a task attached to the presented target word might be responsible for the activation mainly found in the right hemisphere.

The differentiated priming effect of explicitly and implicitly processed prime words could be due to the time elapsed between prime and target. Many studies found that implicit priming does affect the N4 mainly at short SOAs (Kiefer & Spitzer, 2000; Ruz et al., 2003). It is surprising that the N4 effect is not modulated by the position of the exogenous cue in the pre- or post-change scene although there is a profound difference in SOAs between the exogenous cue and target in these two conditions. The SOA between the prime presented in the pre-change scene and the target word is 1750 ms and between the prime presented in the post-change scene and the target word is 500 ms. Kiefer (2002) stated that the N4 in the classical semantic priming paradigm is modulated by implicitly processed primes up to SOAs of 500 ms. Why then is there no modulation by the position of the implicitly processed exogenous cue? According to Kiefer (2002) the length of SOA that produces an N4 effect in reaction to implicit primes varies with the task presented. It seems that the visual search paradigm change blindness requires SOAs shorter than 500 ms to produce an N4 effect to implicit primes. This could be due to competing processes used to execute the change detection task. The resources required to perform the visual search might significantly reduce the resources open to lexical analyses, which shortens the SOA at which the N4 could be modulated by implicit primes (Kiefer & Spitzer, 2000). Irrespective of the explicit or implicit mode the exogenous cue captured attention, is processed, and stable representation were formed.

The interaction of endogenous perceptual and exogenous lexical semantic cues

That the endogenous cue was successful in controlling attention allocation and hindered the attentional capture by the exogenous cue was revealed by the reduction of change detection in reaction to the presentation of a concurrent invalid endogenous cue. The endogenous cues were valid in two thirds of the trials. This ensured focused attention on the position of the endogenous cue and limits the resources available for exogenous attentional capture as argued by Besner et al. (2005) and Stolz and Stevanovski (2004). Thus even in the invalid cue condition the endogenous cue directed attention to a spatial location and did not left enough attentional resources for the lexical semantic cue to capture attention to the word where the change actually took place. The presentation of an invalid endogenous cue significantly reduced change detection in comparison to trials without endogenous cues where the exogenous cue was processed and formed stable visual representations.

The endogenous control of attention to the cued location also prevented the formation of stable visual representations for the exogenous lexical semantic cues. This is evident in the lack of a semantic priming effect in the target word due to the perceptual endogenous cue that led to the focusing of attention away from the prime word. Invalid cues elicited a positive increase in the 275-400 ms time range at parieto-central electrodes for experiment 1 and an enhanced N3 for fronto-central and frontal-right electrodes for experiment 2. Under the no endogenous cue condition the exogenous cue should be processed rather than in the invalid endogenous cue condition where the endogenous cue should draw attention away from the exogenous one. If prime processing was reduced in the invalid cue condition it is to be expected that more resources have to be allocated to the processing of the target word as opposed to the no endogenous cue condition where prime processing should not be impaired. Therefore word processing should be expected when presented with the target word following the no cue condition. If the prime was embedded in the pre-change scene a positive increase in the 275-400 ms time range could be seen in reaction to the invalid cue. In line with the argument that word processing is reduced in the invalid cue condition this effect could be a P3 like modulation that signals a mismatch between a task in which word processing is irrelevant and the presented target word. In the same vein, the enhanced N3 for target words following primes embedded in the post-change matrix could be due to the fact that the post-lexical analyses needs more resources in the invalid cue condition than in the no endogenous cue condition where further word processing is expected.

Therefore, these results are in line with the literature stating that endogenous cue predominate in their influence over exogenous cues (Besner et al., 2005; Stolz & Stevanovski, 2004). Dell'Acqua et al. (2007) argue that the predominance of the endogenous attention allocation is due to the experimental design used by Besner et al. (2005) and Stolz and Stevanovski (2004). These authors did not (at least not continuously) present the endogenous cue simultaneously with the exogenous cue. According to Dell'Acqua et al. this could lead to enhanced attentional focusing on the location endogenously cued and hinder attentional capture by the exogenous cue. Dell'Acqua et al. presented the exogenous cue simultaneously with the endogenous cue and found attentional capture by the exogenous cue despite 100% endogenous cue validity. In the presented experiments the endogenous cue was presented prior to the change matrices and thereby also prior to the exogenous cue. Following this argument, the experimental design might be an alternative explanation for the results found in the comparison of endogenous and exogenous cueing effects. Hence, it is not clear if the predominance of the endogenous cue is due to its influence on the limited capacity system of attention or the presentation of endogenous cues prior to exogenous cues in the experimental design. Future research should consider these two explanations and present both cues simultaneously as Dell'Acqua et al. (2007) did, but with an additional variation of demands on the attentional system to differentiate between the two explanations.

Conclusion

The first two experiments clearly show that exogenous lexical semantic cues are processed in a visual search task. The influence of this processing on visual search however depends on the processing mode (explicit or implicit processing). The differentiation between the results of explicit and implicit processing is in line with the assumption that both processing modes are independent. Debner and Jacoby (1994) showed that explicit and implicit perception influences tasks differently and thus could be dissociated. The same is true in the present experiments. Explicitly processed exogenous cues reduce change blindness dependent on the task relevance of the cue (i.e. its position in the pre- or post-change scene). This is not the case if the exogenous cue is implicitly processed. Explicit and implicit processing also differs in the ERPs elicited on the target word. Explicit processed exogenous lexical semantic cues elicited an N4 priming effect whereas implicitly processed primes modulated the earlier N3 component. Independent of the specific ERP components it is clear that exogenous cues are able to form stable representations under both processing modes.

The prior presentation of endogenous cues influences the resources available for attentional capture by the exogenous cue. An invalid endogenous cue attenuates change detection notwithstanding the possibility to detect the change if the exogenous cue would be able to capture attention. Furthermore it hinders the formation of stable visual representations of the lexical semantic cue as expressed in the ERP data. Nevertheless it is difficult to compare the influence of the exogenous lexical semantic and the endogenous perceptual cue. As mentioned above the presentation sequence might lead to the conclusion of a general predominance of endogenous control of attention over the exogenous capture of attention that could not be true. If both cue types are simultaneously presented this predominance might not be found as shown by Dell’Acqua et al. (2007). Furthermore, one cue type is semantic and the other perceptual. It is clear that semantic and perceptual cues are processed in a visual search paradigm and influence change detection. Nevertheless the predominance of the endogenous cues could also be due to their perceptual format. This format might be more contingent with a visual search task than lexical semantic cues. To further study the influence of exogenous cues on visual search the third and fourth experiment are designed. In the following experiments both semantic and perceptual cues are presented simultaneously as exogenous cues to allow comparing their influence on visual search.

Experiment three and four

Semantic versus perceptual exogenous cueing

Experiment three

The first two experiments showed that exogenous semantic cues are able to capture attention and form stable representations in the change blindness paradigm. Nevertheless the influence of endogenous perceptual cues on visual search is stronger. This might depend on the cue attributes (semantic vs. perceptual) used in the previous experiments. Thus the object of the third experiment is to determine the role of semantic and perceptual exogenous cues for visual search. What guides our visual attention when we process a complex visual scene without overt endogenous cues to help the guidance of attention? According to Henderson (2003) the features of the scene which attenuate or enhance visual search depend on local perceptual or global semantic characteristics. Thus I will at first review evidence and theoretical background favouring either the role of perceptual or semantic stimuli features for visual search as well as the role of context for these features. Afterwards change blindness experiments comparing the role of these features are presented. Closing the introductory section I will present the specific research question and subsequent hypothesis aimed to answer the questions if semantic or perceptual exogenous cues are predominant in visual search and if stable representations are formed for the pre- or post-change scene.

The influence of local and global stimuli features on visual search

Basic visual features, like spatial orientation, colour, intensity, or contrast, define the local perceptual characteristics. This information is combined in a saliency map as illustrated in figure 22 (Itti & Koch, 2000, 2001; Parkhurst, Law, & Niebur, 2002) which guides the spatial distribution of gaze in a bottom-up manner and determines the duration of fixation (Henderson, 2003). In contrast, the extraction of global semantic characteristics depends upon different types of knowledge, such as episodic scene knowledge (knowledge formed from single or repeated encounters with a certain scene, see Henderson & Ferreira, 2004), scene-schema knowledge (knowledge formed about types of scenes, see Friedman, 1979), and task-related knowledge (knowledge formed from strategies used in certain tasks, see Henderson et al., 1999).

Henderson (2003) states that both attributes determine the distribution of attention in scene perception: the top-down memory based extraction of semantic attributes and the bottom-up stimulus based information processing. Numerous empirical studies have also shown that the distribution of attention can be automatically guided by global or local features (Chun & Marois, 2002). The same could be shown for semantic features in the above-presented experiments.

Processing hierarchies of local and global stimuli features

It remains unclear whether the two processes can also act independently. The classical view of visual information processing states a hierarchy from the processing of low-level simple to high-level combined visual features (Hubel & Wiesel, 1968), and predicts that the guidance of visual attention is primarily based on local features. In contrast, Hochstein & Ahissar (2002) proposed a *reversed hierarchy of vision*. Following the results of a perceptual learning task, they concluded that controlled information processing starts at a high level where the visual information is already generalized and categorized ("*vision at a glance*"). From there, the hierarchy is reversed. Local information is only encoded when detailed information about an object or scene is needed in the so-called "*vision with scrutiny*". Following this model, visual search is primarily determined by the extraction of global information. According to the *reversed hierarchy,* global information should have a temporal advantage over local information in (time pressured) visual search. The *reversed hierarchy theory* is supported by the finding that global scene attributes can be extracted without previous grouping or segmentation of local information (Torralba & Oliva, 2003). Torralba and Oliva (2003) computed image statistics of different scenes, objects, categories, and contexts. They were able to show that the average power spectrum of a visual display differs for specific categories or containing objects. The average power spectrum is formed through the computation of distribution of orientations, the spatial frequency distribution, the depth/volume of environment, and the number of pixels. According to the authors subjects are able to extract global scene attributes from these low-level features and this leads to top-down modulation of perceptual processing in the visual display. Thus, it is in line with the finding that global/semantic context processing affects local processing like gaze control and scan pathways (Henderson, 2003).

The influence of context on visual search and the processing of perceptual and semantic stimuli features

As already stated in the general introduction, context formation or categorization seems to be a general mechanism in visual processing and can be used for information reduction (Antal et al., 2001; Antal et al., 2000; Bilalic et al., 2009; Fabre-Thorpe et al., 2001; Henderson, 2003). According to a study by Peelen, Fei-Fei and Kastner (2009) categorization serves as a top-down biasing mechanism that enables us to represent objects of the searched for category even outside the focus of attention. This biasing mechanism of context or category is furthermore able to define which information can act as an exogenous cue in visual search. The context does not only define which objects are semantically salient (i.e. not consistent with the scene/ scene related knowledge) but also which are perceptually salient according to the saliency maps (De Graef, Christiaens, & d'Ydewalle, 1990;

Friedman, 1979; Henderson, 2003; Henderson & Ferreira, 2004; Henderson et al., 1999). Salient perceptual information (according to different factors like orientation, colour/hue, depth, contrast, etc.) is combined into a perceptual saliency map as illustrated by figure 22.

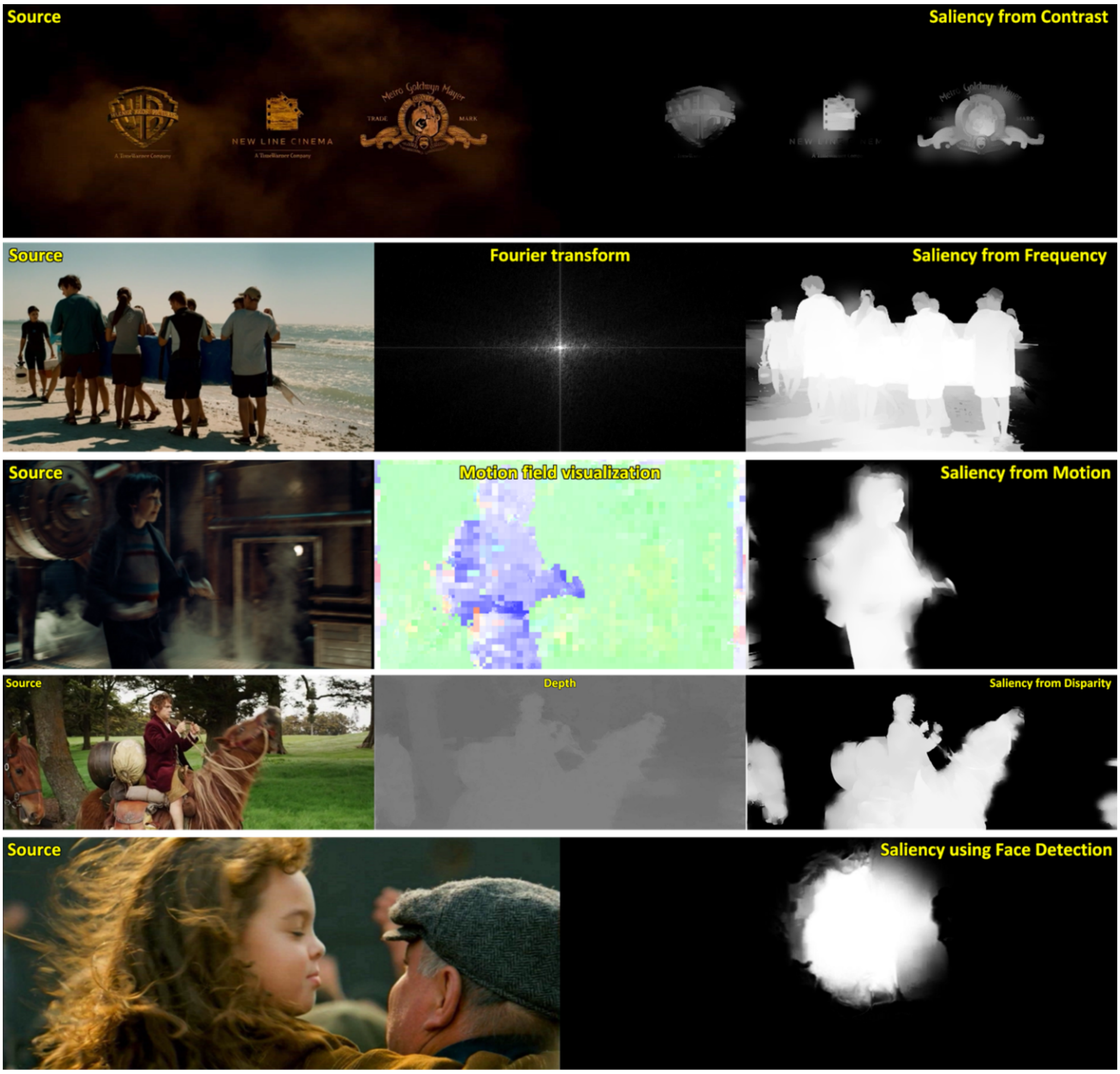


Figure 22. Saliency maps according to different factors computed using algorithms designed by Vatolin, Gitman, Voronov, Novikov, and Matyunin for the Graphics and Media Lab. Retrieved August, 29th, 2014 from http://graphics.cs.msu.ru/en/node/1009 (Vatolin, Gitman, Voronov, Novikov, & Matyunin). Reprinted with permission from Dmitriy Vatolin.

According to Torralba and Oliva (2003) the encoding of scene category or object identity from low-level features leads to top-down modulation that defines regions of interest and influences visual processing (see also Bilalic et al., 2009). The highlighting of regions of interest through top-down modulation of semantic information leads to the preferential processing of perceptual information in these regions. Hence, top-down modulation from the extraction of category/context information is combined with the perceptual salient stimuli features and used to form the combined saliency map (Henderson, 2003).

Scene context and exogenous cues in change blindness studies

The role of context for the definition of exogenous cues was tested in change blindness studies. Henderson and Hollingworth (2000) showed that semantic deviants to a scene context were able to capture attention and facilitate change detection. Rensink et al. (1997) showed that central interest regions in a context likewise captures attention and changes in these regions are better detected than changes in marginal interest regions. According to Kelley et al. (2003) this effect of central interest regions is stable if the changes are matched for visual salience and they furthermore showed that context is relevant for the deployment of attention and thereby facilitates change detection. This categorisation of single objects into a scene/context also defines the salience of perceptual stimuli features. Henderson (2003) argues that a purely stimulus based salience map is combined with knowledge based saliency maps in a categorized context/scene that enhances perceptual stimuli features with high salience in the combined map. Stirk and Underwood (2007) directly compared the influence of perceptual and semantic salience on change detection. They presented their participants with a flicker paradigm using photographs of naturalistic scenes. The change constituted an exchange of objects. The authors used changes of objects that varied the semantic congruence to the context and perceptual salience resulting in four conditions (figure 23). They found that scene inconsistent changes facilitated change detection but visually high salient changes did not differ from low salient ones in detection rates and concluded a predominance of semantic exogenous cues for visual search in naturalistic scenes. Pringle, Irwin, Kramer, and Atchley (2001) also compared the influence of perceptual and semantic changes and used the flicker paradigm and photographs. Changes were constituted by colour or location changes or the appearance/disappearance of objects. The authors varied the perceptual salience of the change and its meaning for the scene. They, in contrast to Stirk and Underwood, found that perceptual salient changes facilitated change detection whereas semantic salient changes did so only if perceptual salience was low. They thus concluded the predominance of perceptual exogenous cues with the capture of attention by semantic exogenous cues only if the predominant perceptual system did not provide a salient cue.

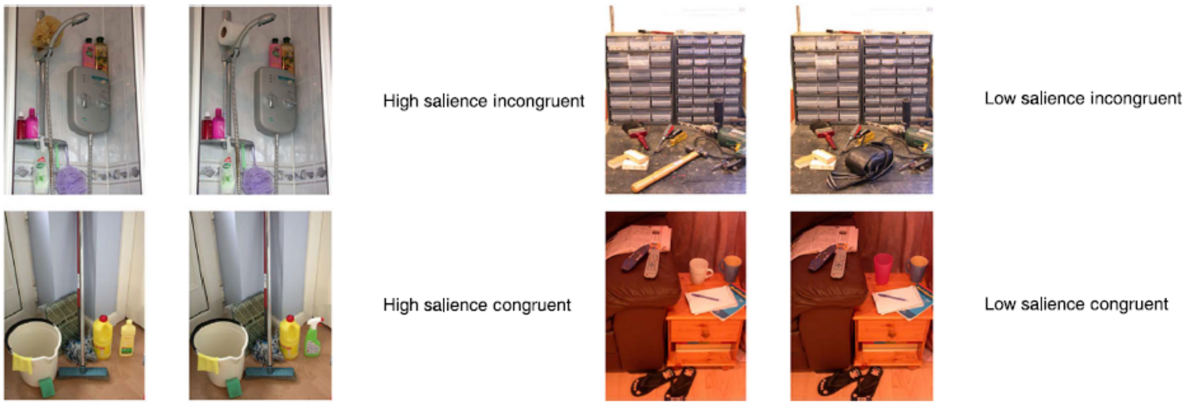


Figure 23. Examples for the stimuli and conditions used in the study “Low-level visual saliency does not predict change detection in natural scenes” by Stirk & Underwood (2007), *Journal of Vision, 7*, p. 5. Reprinted with permission by Association for Research in Vision and Ophthalmology, copyright 2007 and from Jonathan Stirk.

The effects of perceptual and semantic exogenous cues on visual search

The present experiment aims to differentiate the effects of exogenous semantic and perceptual deviants in a change blindness paradigm as well as the stability of representations from the pre- and post-change scene (Simons, 2000). In order to control for the context effects, a categorized arrangement was used that allows defining the deviance of an object by its physical appearance and by its categorical uniqueness (see figure 24a and b). Thus in contrast to the experiments reviewed in the previous section no photographs of real world scenes were shown but a categorical sorting of line drawings. This setting allows more exact controlling of perceptual and semantic object features.

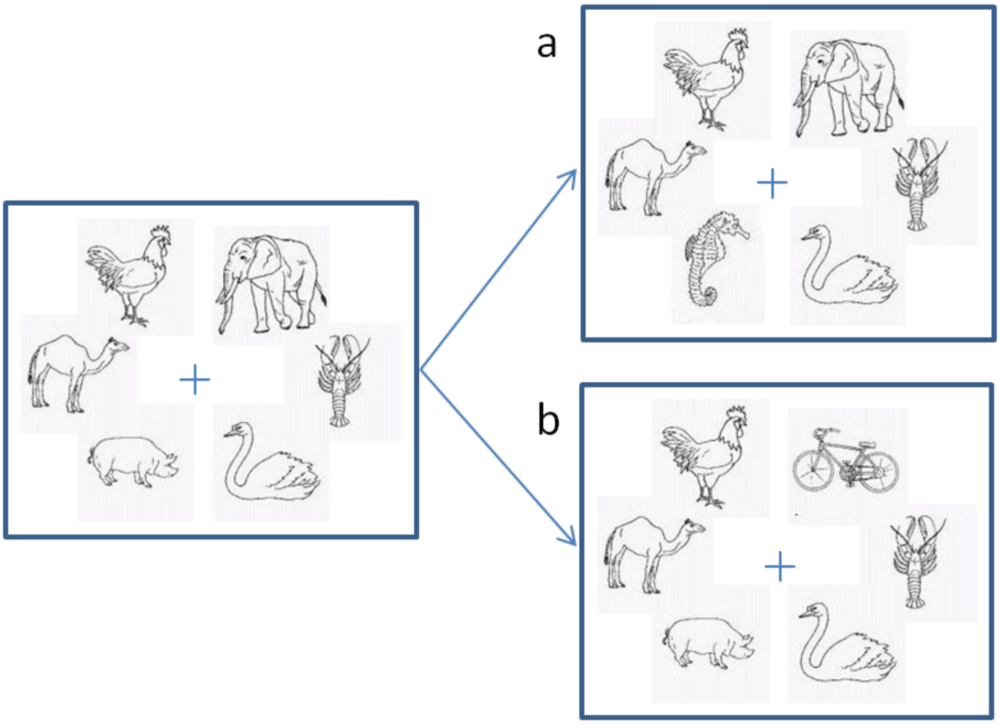


Figure 24. In the present experiment the original scene is constituted from six single objects sorted into categories and the modified scene is constituted from the exchange of one of the six original single objects. a) change object is a perceptual deviant, b) change object is a semantic deviant.

Therefore the influence of perceptual and semantic deviance to the categorization context on change detection rates can be directly assessed in this experimental design. Deviants capture attention as is clear from the literature (Hollingworth & Henderson, 2000; Theeuwes, 1992; Todd & Marois, 2004). Therefore the deviancy of a stimulus can be used as an exogenous cue. In the present experiment semantic as well as perceptual deviants are used as exogenous cues. Reaction times are speeded with the confidence participants have in their decision, which is presumed to be higher when attention is allocated to the change position by the exogenous cues (Eimer & Mazza, 2005; Kutas & Van Petten, 1994; Mitroff et al., 2002). From the contradicting results of earlier studies the question arises:

Q 1: Are perceptual or semantic exogenous cues predominant in their facilitating effect in visual search through the capture of attention?

As is clear from the Pringle et al. (2001) experiment, a perceptual salient change is able to capture attention and facilitate change detection. In the present experiment the perceptual deviancy between the pre- and post-change item was varied. Major deviances differ from the pre-change item to a high degree on the factors spatial expansion, number of pixels and brightness whereas minor deviances differ to a much lesser degree from the pre-change item. Hence, it can be hypothesized that:

H 1a: Major perceptual deviances elicit higher detection performances and faster reaction times than minor ones.

From the experiments using semantic incongruent stimuli to a context it is clear that semantic incongruent (deviant) stimuli facilitate change detection (Hollingworth & Henderson, 2000; Stirk & Underwood, 2007). The present experiment uses a categorized arrangement as the context. The semantic deviancy of a stimulus was varied by using exchanges between stimuli from different categories as major deviances and changes between stimuli from the same category as minor deviances. Therefore major semantic deviances are incongruent to the category context. Thus it can be hypothesized that:

H 1b: Major semantic deviances elicit higher detection performances and faster reaction times than minor ones.

It is, however, from the conflicting results concerning the advantage of perceptual or semantic object features for visual search not predictable which exogenous cue feature shows better detection rates/speeded reaction times or if perceptual and semantic deviants do not differ in the present controlled context condition. To answer the posed question on the predominance of perceptual or semantic features for visual search additional information might be obtained using electrophysiological recordings. ERP components provide evidence whether local or semantic deviances are processed independently and/or with a different time course. Hence, event-related brain potentials (ERPs) were additionally recorded. Thus it can be questioned:

Q 2: Do perceptual and semantic exogenous cues differ in their ERP signatures?

Previous studies have shown that the detection of visual or semantic deviants triggered signatures of implicit processing in ERPs (Li, VanRullen, Koch, & Perona, 2002; Matt et al., 1992). There is additional evidence that categorization of single objects is already concluded within 150 ms after stimulus onset (Fabre-Thorpe et al., 2001; VanRullen & Thorpe, 2001). The early ERP components P1 and N1 which are assumed to be modulated by focused attention in visual search are analysed (Luck, Heinze, Mangun, & Hillyard, 1990). The P1 was shown by Luck et al. to facilitate input at the location attention is already focused on and the N1 to orient attention to the location of a stimulus relevant in the present task (Luck et al., 1990). The time range of these components (80-130 ms for the P1, 100-200 ms for the N1) lies before or within the time range in that categorization is concluded. Experiments that explored these early components used single letters or simple geometrical forms presented either at attended or not attended locations and found modulation of the P1 and N1 for stimuli at attended locations. It seems clear that successful cueing through the exogenous cues that are said to capture attention to stimuli location should enhance the P1 and N1. Nevertheless given the fact that semantic cues rely on the categorisation of the items they might not influence these early components. Therefore it can be hypothesized:

H 2: A modulation of the P1 and N1 components are triggered by perceptual deviants, but are unlikely to be triggered by semantic deviants that need to be categorized to be effective.

As stated above ERP components might show differentiated processing able to answer the question if semantic or perceptual features are predominant in visual search. Components that might show a difference in processing are the N2pc and the P3. Thus the question is if:

Q 3: Is the predominance of semantic or perceptual exogenous cues for visual search mirrored in their ERP signatures?

Attentional shifts in visual search tasks are also related to the N2pc component: This posterior negativity is more pronounced contralateral to the spatial position of the attended item in a visual search display (Schankin & Wascher, 2007, 2008). The time range of the N2pc lies between 200 and 300 ms. Therefore categorisation is already concluded before the N2pc is elicited and semantic deviants (which rely on categorisation) are also able to modulate the N2pc when they capture attention. Hence the N2pc is able to show if perceptual and/or semantic deviants are able to capture attention. If one deviant type predominantly elicits the N2pc inferences can be made to information processing hierarchies and the predominance of this stimuli feature for visual search. The same is true for the P300 complex that is assumed to reflect deviances in the post-change display. Following previous studies the component signals a mismatch between the current percept and a stored representation (Niedeggen et al., 2001). It is likely that semantic as well as perceptual deviants should elicit a corresponding P300 effect. If one exogenous cue feature is predominant it might show enhanced processing of the N2pc and/or P3 as compared to the other one. Thus it can be hypothesized:

H 3: The N2pc and P3 are triggered by attentional capture of perceptual and semantic exogenous cues.

According to the contradicting evidence found in the behavioural experiments on the predominance of semantic or perceptual features in visual search it is unclear which exogenous cue feature elicits higher potentials. An enhanced processing of these components in reaction to the semantic exogenous cues might speak for the proposed vision at a glance and the reversed information processing hierarchy (Hochstein & Ahissar, 2002) and a predominance of semantic features for visual search. Whereas enhanced processing of the components in reaction to perceptual exogenous cues might be in favour of the classical view of information processing hierarchy (Hubel & Wiesel, 1968) and the predominance of perceptual features for visual search.

Are perceptual or semantic exogenous cues able to form stable representations?

A further question arising from the importance of perceptual and/or semantic exogenous cues is the one after the influence of these stimuli features on the representation of the change items.

If the perceptual or semantic exogenous cues do influence detection performance do they also influence the storage of representations? As seen from the semantic priming effects in the previous experiments exogenous cues are able to form stable representations irrespective of their position in the pre- or post-change. It thus seems clear that cueing forms stable representations of the pre- and post-change scene. Nevertheless as was reviewed in the introductory section many studies on change blindness show evidence for the storage of the post- but not the pre-change scene. This might be due to overwriting (Simons, 2000), retrieval blockage (Yang & Yeh, 2009) or short term memory processes that favour the retrieval of post-change items that are presented more recently than pre-change items (Broadbent & Broadbent, 1981; Vogel, Woodman, & Luck, 2006). Therefore the question is:

Q 4: Are there signs for stable representations of the pre- and/or post-change items?

The exogenous cues as deviances or mismatches to the pre-change item are presented as the post-change item. This cueing design should influence the stability of the pre- and post-change representations as the cueing literature and the previous experiments suggest (Schmidt et al., 2002). Nevertheless, it might be possible that the deviancy of the stimulus serves as a pop-out feature and highlights this item resulting in a more stable representation of the post-change item (Todd & Marois, 2004) and possibly retrieval blockage of the pre-change item by the facilitated representation of the post-change item. To test this the change blindness paradigm is combined with repetition priming. Following the post-change scene either the pre- or post-change item is repeated or a new item (not part of the current stimuli displays) is presented. The recognition of items depends on the confidence with which the decision is made and therefore again varies reaction times (Eimer & Mazza, 2005; Kutas & Van Petten, 1994; Mitroff et al., 2002). According to the mismatch of the deviant and the retrieval blockage theory, it should be hypothesized that:

H 4: The repetition of post-change items shows higher recognition rates and lower reaction times than repeated pre-change items or the presentation of new items.

Unlike the first two experiments the prime in the present experiment is a picture while the target is a word. Stelmack and Miles (1990) showed evidence for a repetition priming effect from picture primes to word targets in the modulation of the N4 component. Hence the question is:

Q 5: Do the pre- and/or post-change items elicit the N4 priming effect?

A stable representation elicits a repetition N4 priming effect (Kiefer & Spitzer, 2000). If the exogenous cues influence the allocation of attention the pre- and post-change items should be stably represented as in the previous experiments. On the other hand, the representation of the deviant items should be more stable and decrease the N4 component in reaction to the repeated target word as stated above. As shown in experiment one and two, implicit and explicit semantic priming elicits different ERP components. Is the same true for repetition priming? According to Schnyer, Allen and Forster (1997) repetition priming modulates the N4 also at the implicit level up to SOAs of 2 seconds. Therefore it is likely that the N4 in reaction to the target is modulated on the implicit and explicit level by stability of representations as varied by the exogenous cue. It can be hypothesized that:

H 5: The repetition of the post-change items elicits an N4 priming effect in contrast to the repetition of pre-change items or the presentation of new items.

Method and Material

Participants

EEG and behavioural data from 24 subjects were recorded. Seven participants had to be excluded from the analyses due to the amount of artefacts in the EEG or a too low number of trials in certain conditions. The analysed data set included only right-handed participants (11 female, 6 male; aged between 21 and 37; mean age: 26.8) with German mother tongue, and normal or corrected-to-normal vision. Six subjects had to be excluded from analysis for the change detection task due to the amount of artefacts in the EEG.

Stimuli

At a viewing distance of 150 cm, the retinal size subtended 7.6° x 7.6° for each image. The target words were between three and 16 letters long resulting in a range of retinal size from 0.96° to 5.03° x 0.27° for capital letters and 0.34° for small letters. Line drawings, words, and numbers were printed in black and presented on a white background resulting in a contrast of 97%. The program was created using E-Prime 2.0 and used the E-Prime SRBox to record reactions (Psychology Software Tools, Inc., Sharpsburg, PA).

Pairs of image configurations were used, consisting of the ‘original scene’ and ‘changed scene’. The images used in the change blindness task were composed out of six single line drawn objects (stimuli taken from Snodgrass & Vanderwart, 1980) arranged in circular order (see Fig.1). In total, 288 images were constructed. In 50% of the images (144 images), single objects were taken from one distinct category (for example animals, food, tableware, see below), and in the remaining 50% (144 images), objects were not categorically related. For each image, a matching modified image was constructed in which one of the six line drawings was exchanged by another line drawing (deviant).

To differentiate between perceptual and semantic deviance effects, the object was modified according to four experimental conditions: a) minor perceptual deviance, but same category, b) major perceptual deviance, but same category, c) minor perceptual deviance and categorical change, and (d) major perceptual and categorical deviance (figure 25). 36 pairs of original and changed scenes per deviance condition were presented in each of the category condition (categorized vs. uncategorized). In the uncategorized control condition the change was realised as a random exchange of stimuli irrespective of perceptual or semantic deviancy between pre- and post-change item.

Perceptual deviance was defined according to three characteristics: (a) horizontal and vertical expansion, (b) number of pixels, and (c) brightness of the drawing. In the condition ‘minor perceptual change’, the original and changed items were matched according to these criteria. In the condition ‘major perceptual change’, only number of pixels was matched, but brightness and horizontal/vertical expansion was varied. Brightness was measured not over the whole picture but over the drawing itself inside its contours. Hence items with a higher horizontal/vertical expansion are brighter than dense drawings.

Semantic deviance was defined as “between” if the change object was chosen from a different category or as “within” if it was chosen from the same category. 10 categories were constructed by sorting the line drawings of the Snodgrass & Vanderwart (1980) battery (the specific categories can be found in the appendix, table 1).

The unsorted images that constitute a control condition were constructed using six images from 10 categories (see appendix, table 1) and a random exchange not regarding semantic or perceptual similarity. Unsorted images were inserted to be able to compare them to sorted ones to evaluate categorisation processes like time to process an image or the predominance of specific categories over others. The control condition was not analysed here because the research questions focus on the difference between semantic and perceptual stimuli features for visual search and not categorisation processes per se.

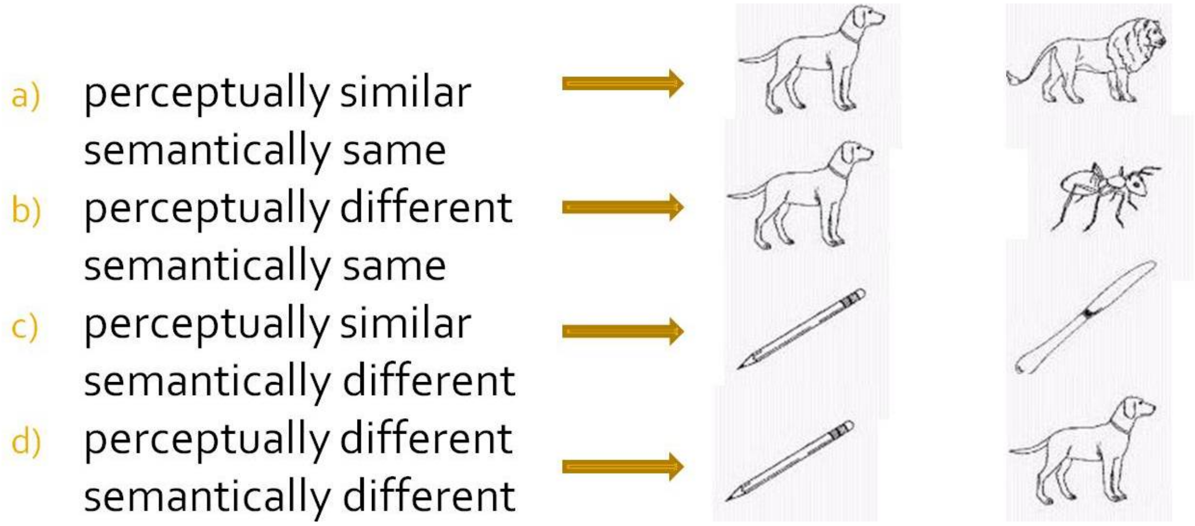


Figure 25. Examples for the four deviance conditions resulting from the variation of perceptual and semantic resemblance.

To evaluate if the exogenous cue facilitated the stability of the visual representation target words were created relating in ⅓ of the trials to the to-be changed line drawing of the original scene or the changed drawing of the changed scene or to an unrelated line drawing (i.e. one not represented in the current scenes but familiar from other scenes).

In order to evaluate the validity of the change detection, a spatial identification procedure was introduced. The subjects were presented with an array of digits (1-6) referring to the positions of the six line drawings presented beforehand.

Experimental design and procedure

In the third experiment, image pairs were presented in a ‘one-shot flicker’ paradigm. Participants’ task was to press a response button as soon as they detected the change. The time window allowed to respond to a change detected was 1500 ms. Following the change detection task a word was presented (500 ms) naming the original, the changed or an unrelated line drawing. The participants were asked to indicate via key press if the corresponding line drawing was present in the scenes irrespective of the exact location of the drawing. For 250 ms the target word was presented only and for the following 1250 ms (250 ms of the remaining target word presentation and 1000 ms of a reaction time window with a blank screen) the participants had time to react. Subjects were at last instructed to press the button on a keyboard corresponding to the position of the changed objects. Subjects were forced to guess if a change has not been perceived *(*see figure 26*)*. The trials were partitioned into 6 blocks with 48 trials each preceded by six uncategorized practice trials.

The execution of the experiments took approximately 45-60 minutes and therefore the whole space of time from the information about the procedure unto the debriefing was about 95-130 minutes.

EEG data recording and analysis

As in the previous experiments, EEG was again recorded (Acquire Application Version 4.3.1, NuAmps Digital EEG amplifier, Neuroscan Labs, Neurosoft Inc., USA) at 25 Ag/AgCl electrodes equidistantly positioned on the scalp and referenced to linked mastoids and electrode position Fcz as ground as well as vertical and horizontal EOGs (vEOG, hEOG).

For each participant and each electrode, artefact-free trials were averaged according to the post-change image and the target word. The post-change images were averaged according to the four combinations of perceptual (minor vs. major deviance) and categorical (within vs. between) similarity. The target word images were averaged according to their relation to the original scene, the changed scene or an unrelated scene (e.g. an item that was not present in the current trial but familiar from the experiment).

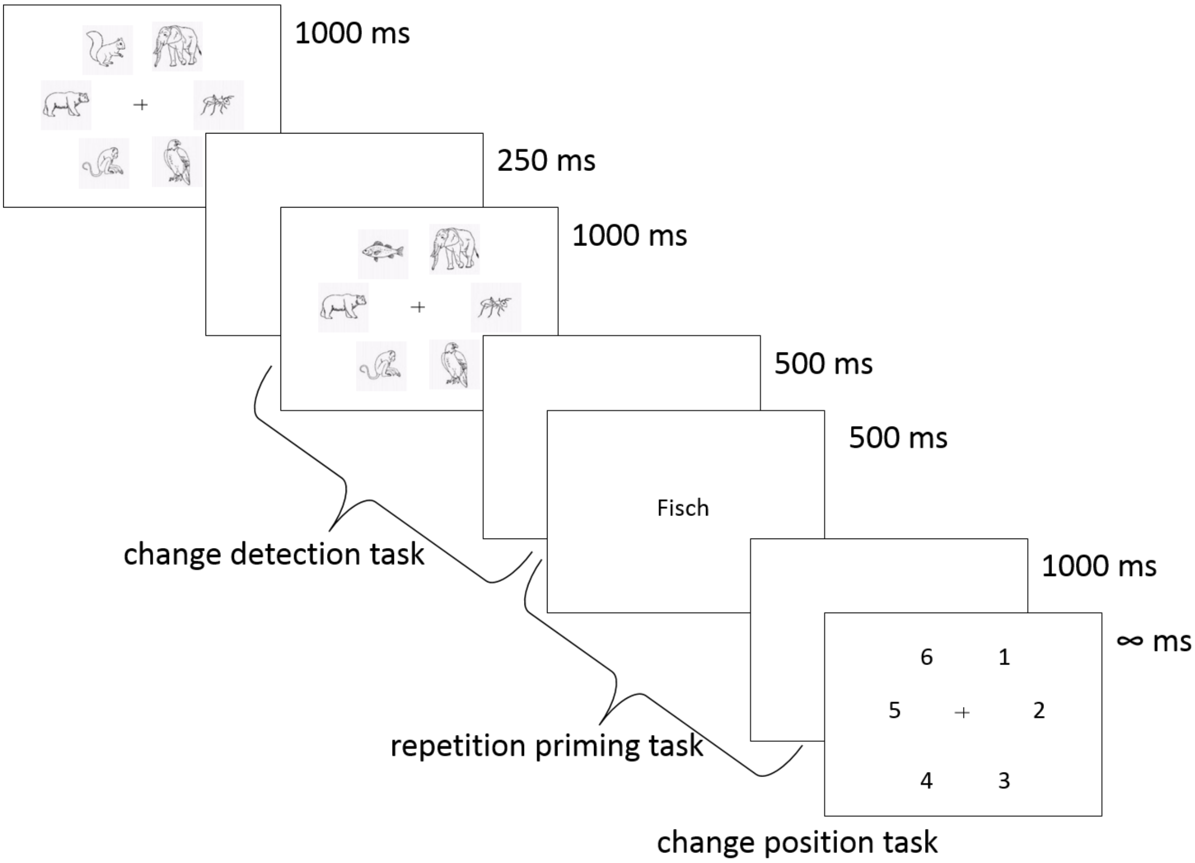


Figure 26. Two images with six circular presented line drawn objects were presented for each 1,000 ms, interrupted by a blank screen for 250 ms. The ‘flicker’ prevented the detection of a local object exchange. Participants had to indicate if they recognized the change with a key press on the E-Prime SRBox. Afterwards the target word was presented for 500 ms and participants had to indicate if the target word was present in the change detection scenes with a key press. At the end of the trial, subjects were to specify on which position (1-6) the change took place via key press.

Since participants were instructed to keep fixation, the local change was presented in one visual half-field. ERP analysis for the post-change scene considered this. Therefore, the lateral position of the electrodes was assigned to the lateral position of the change.

Accordingly, the electrodes were assigned to the factor “hemisphere” (ipsilateral and contralateral to the position of the local change). This procedure was necessary to analyse lateralized components, such as the N2pc (Schankin & Wascher, 2007, 2008), but was also applied to analyse other ERP components of interest in the post-change scene (P1, N1 and P3 component).

Experimental variables

Dependent and independent variables are different for the analyses done to answer the questions posed in the introduction.

Q 1: Are perceptual or semantic exogenous cues predominant in visual search?

The independent variables in the two-factorial repeated measurement design were “semantic similarity” (within vs. between categories) and “perceptual similarity” (minor vs. major perceptual deviance). Dependent variables are the change detection rates for and the reaction times to the change scene. Mean change detection rate was computed for each participant separately for the four experimental conditions. Successful change detection required that (a) subjects indicated to detect a change by pressing the button, and (b) that the subsequent localization of the deviant was correct. Only thus corrected hit rates were used in the analyses.

Q 2: Do perceptual and semantic exogenous cues differ in their ERP signatures?

On the electrophysiological level dependent variables were the ERP potentials in reaction to the onset of the post-change scene. Grand-averaged ERP potentials were used to define the temporal segments reflecting separate ERP components (P1 range: 80-110 ms, N1 range: 120-150 ms, N2pc: 150-180 ms, P3: 300-500 ms). Independent variables in the four-factorial repeated measurement design were again the semantic and perceptual similarity and additionally electrode and hemisphere (ipsilateral vs. contralateral). Visual inspection of the ERP waves led to the extraction of posterior electrodes. The electrodes used in the analyses were P-ipsi and P-contra, PO-ipsi and PO-contra, as well as O-ipsi and O-contra. It is important to note that the ERPs were not separately analysed for detected and missed changes. As stated later in more detail, the detection rate critically depended on the experimental conditions. In case of a major perceptual deviance, for example, the number of missed trials was insufficient for an ERP analysis.

Q 3: Are deviants able to form a stable visual representation for the scene they are presented in?

Independent variable in the one-factorial repeated measurement design of behavioural analyses was origin (pre-change scene, post-change scene, unrelated image). Dependent variables were recognition rates and reaction times to the target word.

Q 4: Do the pre- and/or post-change items elicit the N4 priming effect?

On the electrophysiological level dependent variables were the ERP potential in reaction to the onset of the target word. Grand-averaged ERP potentials were used to define the temporal segment reflecting the ERP component (N4: 350-500 ms). To account for topographical differences, the independent variables caudality (frontal, central, parietal) and laterality (left, middle, right) were included in the analyses resulting in a three-factorial repeated measurement design. Electrodes were assigned in the following matter to the topographical factors (1) frontal-left: F7, F3, (2) frontal-middle: Fz, Fc5, Fc6, (3) frontal-right: F4, F8, (4) central-left: T7, C3, (5) central-middle: Cz, Cp5, Cp6, (6) central-right: C4, T8, (7) parietal-left: P7, P3, O1, (8) parietal-middle: Pz, Oz, (9) parietal-right: P4, P8, O2. The repetition priming task immediately followed the change detection task. To prevent motor potentials from the reaction to detected changes from overlapping the ERP Potential of the repetition priming task only previously change blind trials are considered. Due to the fact that the N4 is the dependent variable furthermore only not explicitly recognized trials are analysed to prevent motor potentials in the repetition task to overlay the N4.

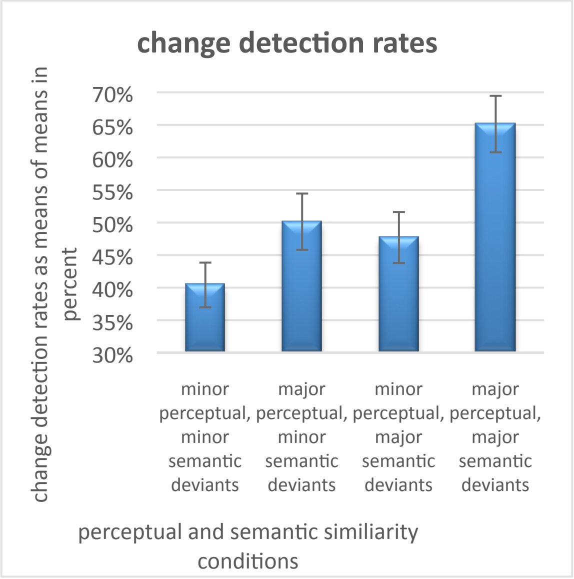
Results

Q 1: Are perceptual or semantic exogenous cues predominant in visual search?

Behavioural Data (figure 27):

Participants detected the change between the images in about 40-65% of the trials depending on the variation of perceptual and semantic similarity. As shown in figure 27, major perceptual deviance increased the detection rate as well as a categorical deviance. Correspondingly, the repeated measures analysis of variance (ANOVA) revealed main effects of perceptual similarity (F (1, 16) = 30.8, $p < 0.001$, $\eta_p^2 = 0.644$) as well as of semantic similarity (F (1, 16) = 20.03, $p < 0.001$, $\eta_p^2 = 0.541$) and a significant interaction (F (1, 16) = 4.44, $p = 0.050$, $\eta_p^2 = 0.207$). All pairwise t-tests are significant but the effect is less pronounced for changes between vs. within a category if the perceptual deviancy is minor (see table 2).

The repeated measures ANOVA with the factors semantic and perceptual similarity for the reaction times to detected changes revealed no significant effects (semantic similarity: F (1, 16) = 2.19, $p = 0.157$, $\eta_p^2 = 0.114$; perceptual similarity F (1, 16) = 2.99, $p = 0.102$, $\eta_p^2 = 0.150$, semantic*perceptual similarity F (1, 16) = 2.59, $p = 0.126$, $\eta_p^2 = 0.132$).



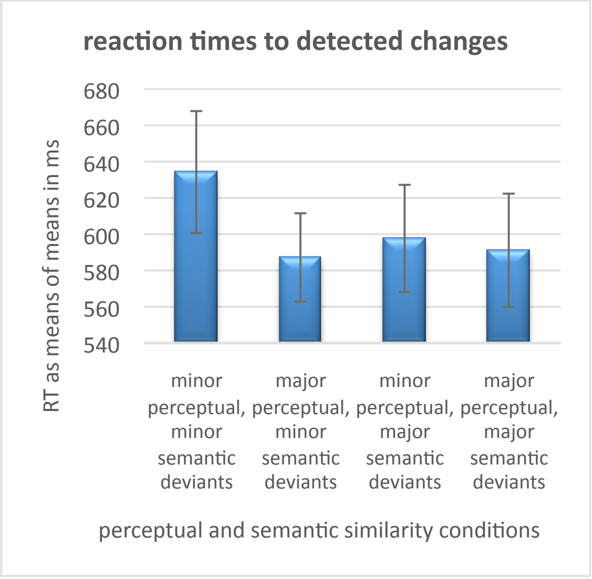


Figure 27. Left side: Change detection rates (in percent) for the four experimental conditions with standard errors as error bars. Right side: Reaction times to detected changes (in ms) for the four experimental conditions with standard errors as error bars.

Table 2

Pairwise t-tests for the differences between minor and major deviances under the semantic similarity conditions (line one and two) and the perceptual similarity conditions (line three and four)

		T	df	significance (two-tailed)
within category changes	minor - major perceptual deviances	-3,848	16	,001
between category changes	minor - major perceptual deviances	-4,976	16	,000
minor perceptual deviancy	minor - major semantic deviances	-2,208	16	,041
major perceptual deviancy	minor - major semantic deviances	-5,246	16	,000

Q 2: Do perceptual and semantic exogenous cues differ in their ERP signatures?

ERP Data (figure 28):

Grand-averages for perceptual and semantic deviants show an enhancement for minor perceptual deviants ipsilateral to the change at the P1 and N1 time interval and a pronounced enhancement for major perceptual deviants in the P3 time interval. The semantic deviants show only an enhancement for within category changes ipsilateral to the change in the N2pc time interval. The analysis of the early components P1, N1, and N2pc as well as the P3 were focused on the posterior electrodes (electrode pairs at parietal (P), temporo-parietal (PT), occipital (O) leads). At these leads, the components were found to be the most pronounced (see Figure 28). Moreover, the analysis of other electrode locations did not reveal any effect of the experimental variations.

The repeated measures analysis of variance (ANOVA) for the P1 time interval (80-110 ms) revealed a significant main effect of perceptual similarity (F (1, 16) = 5.25, p = .035, η_p^2 = 0.236) with minor perceptual deviants enhancing the P1 amplitude as well as a significant effect of electrode. Furthermore the effect of electrode was significant (F (2, 32) = 5.99, p = .011, η_p^2 = 0.261) but no other significant effect or interaction could be found for semantic similarity*electrode*laterality (F (2, 32) = 1.14, p = .330, η_p^2 = 0.063), perceptual similarity*electrode (F (2, 32) = 3.06, p = .062, η_p^2 = 0.152), semantic*perceptual similarity*electrode*laterality (F (2, 32) = 1.88, p = .173, η_p^2 = 0.099) or any of the other effects or interactions reached significance (Fs < 1).

The repeated measures ANOVA in the N1 time range (120-150 ms) again showed a main effect for perceptual similarity (F (1, 16) = 4.48, p = .049, η_p^2 = 0.209) indicated by significant enhancement if minor perceptual deviances were presented. Additionally, the factors electrode (F (2, 32) = 10.36, p = .001, η_p^2 = 0.379), and hemisphere laterality (F (1, 16) = 7.6, p = .013, η_p^2 = 0.309) were significant although they did not interact with either experimental factor (semantic or perceptual similarity). The latter effect indicated an increase in N1 amplitude for changes per se at ipsilateral leads. No further significant effects or interactions could be found for electrode*laterality (F (2, 32) = 1.87, p = .172, η_p^2 = 0.099), semantic similarity*laterality (F (1, 16) = 1.48, p = .241, η_p^2 = 0.080), perceptual similarity*laterality (F (1, 16) = 2.05, p = .171, η_p^2 = 0.107), perceptual similarity*electrode*laterality (F (2, 32) = 1.16, p = .318, η_p^2 = 0.064), semantic*perceptual similarity (*F* (1, 16) = 2.37, *p* = .142, η_p^2 = 0.122), or any other effects or interactions (*F*s < 1).

According to Figure 28, the N2pc effect (150-180 ms) is visible at the contralateral leads. Nevertheless, no significant effect of hemisphere was obtained in the ANOVA (*F* (1, 16) = 4.21, *p* = .056, η_p^2 = 0.199). However, the analysis in this time range indicated a main effect of semantic similarity (*F* (1, 16) = 6.88, *p* = .018, η_p^2 = 0.288) corresponding to a significant increase in negativity induced by a change within the same semantic category. No other significant effects or interactions were found for electrode*laterality (*F* (2, 32) = 1.94, *p* = .172, η_p^2 = 0.102), semantic similarity*electrode*laterality (*F* (2, 32) = 1.19, *p* = .313, η_p^2 = 0.066), semantic*perceptual similarity*laterality (*F* (1, 16) = 1.09, *p* = .311, η_p^2 = 0.060) or any other effects or interactions (*F*s < 1).

The repeated measures ANOVA for the P3 time interval (300-500 ms) resulted in a main effect for perceptual similarity (*F* (1, 16) = 12.19, *p* = .003, η_p^2 = 0.418), electrode (*F* (2, 32) = 3.84, *p* = .043, η_p^2 = 0.184), and hemisphere (*F* (1, 16) = 9.89, *p* = .006, η_p^2 = 0.368) as well as an interaction of electrode and hemisphere (*F* (2, 32) = 2.32, *p* = .041, η_p^2 = 0.187). Major perceptual deviances elicited significantly higher amplitudes of the P3 component. The hemisphere effect is due to a higher positivity at ipsilateral leads (*t* (16) = -3.14, *p* = 0.006) which is most pronounced at the parietal (*t* (16) = -2.12, *p* = 0.049) and temporo-parietal electrode pair (*t* (16) = -3.38, *p* = 0.004).

No further significant effects or interactions were found for semantic similarity*electrode (*F* (2, 32) = 2.32, *p* = .117, η_p^2 = 0.120), semantic similarity*electrode*laterality (*F* (2, 32) = 1.9, *p* = .169, η_p^2 = 0.101), perceptual similarity*electrode (*F* (2, 32) = 2.29, *p* = .129, η_p^2 = 0.119), semantic*perceptual similarity (*F* (1, 16) = 1.34, *p* = .262, η_p^2 = 0.073) or any other effects or interactions (*F*s < 1).

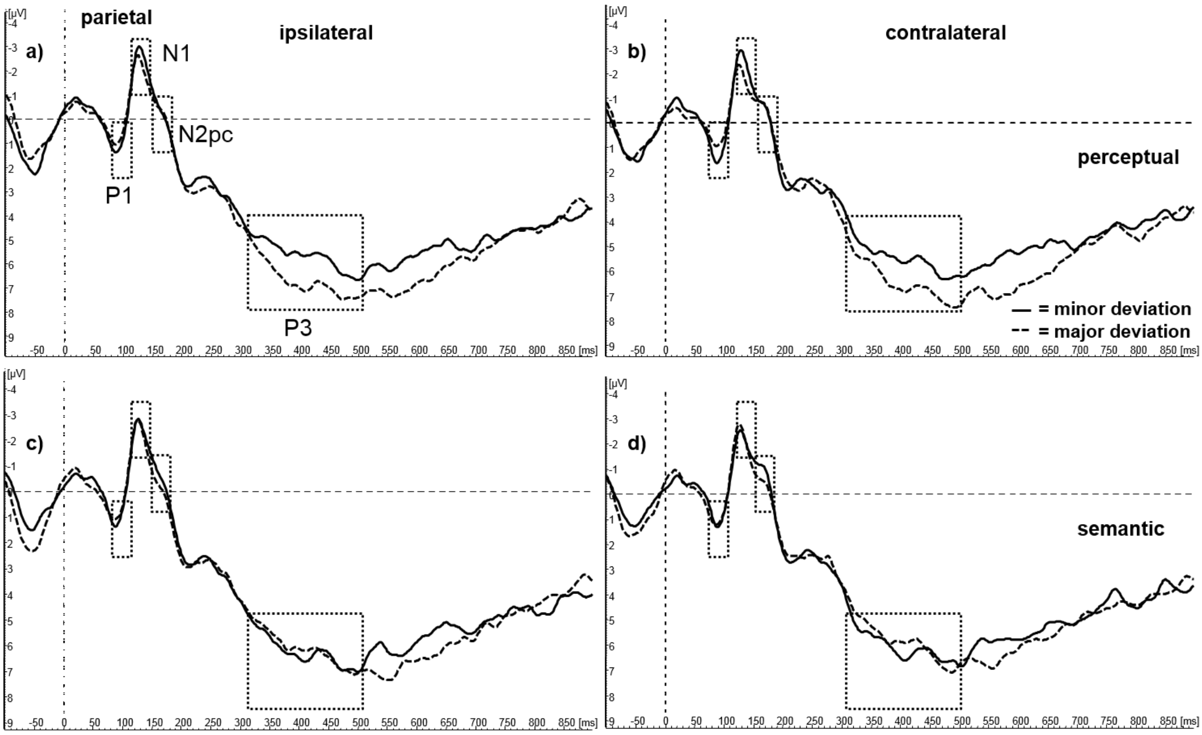


Figure 28. Grand averages for the effect of perceptual (upper row, a and b) and semantic deviations (lower row, c and d) at the ipsilateral (left side, a and c) and contralateral (left side, b and d) parietal electrode. Continuous lines are minor perceptual deviants/same category; dashed lines are major perceptual deviants/different category. Dashed frames highlight the time segments for the ERP components P1, N1, N2pc, and P3.

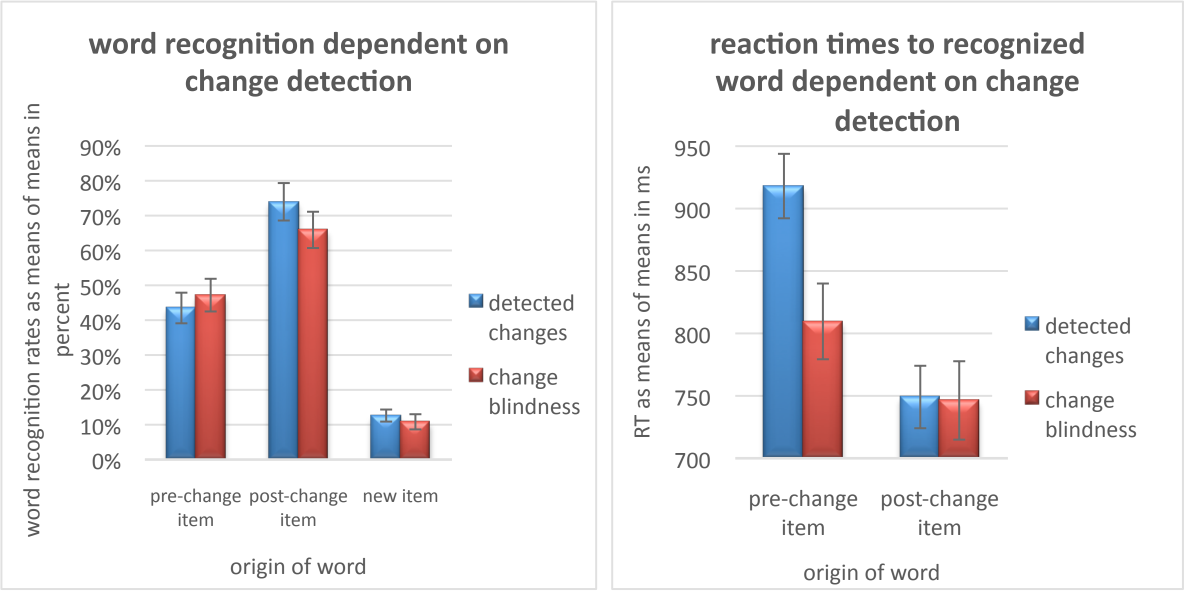
Q 3: Are deviants able to form a stable visual representation for the scene they are presented in?

Behavioural Data:

The repetition priming task (using the target word presented after the post-change scene) was designed to investigate if the exogenous cue led to stable visual representations of the post-change image (where it was presented) in comparison to items from the pre-change image or new items. Therefore recognition rates and reaction times to the pre-change item, the post-change item or a new item which was not present in the trial but also known from the set of used images in the experiment.

Participants recognized the word in 12 % of the trials in the new item condition, in 44.1 % of the pre-change condition and in 72.2 % of the post-change condition. The repeated measures ANOVA showed unsurprisingly a significant main effect of origin of word (F (2, 32) = 112.16, $p < 0.001$, $\eta_p^2 = 0.875$). Post-hoc tests revealed significantly higher recognition rates for the post-change item in comparison to the pre-change (t (16) = -6.54, $p < 0.001$) and new item (t (16) = 13.51, $p < 0.001$) and also higher recognition rates for the pre-change item as compared to the new item (t (16) = 10.07, $p < 0.001$).

According to the extremely low number of recognized new items the repeated measures ANOVA for the analyses to the reaction times to recognized words did only consider the reaction times to pre- and post-change items. The ANOVA showed a significant main effect of origin of word (F (1, 16) = 40.57, $p < 0.001$, $\eta_p^2 = 0.717$) with significantly faster reaction times to post-change items.


word recognition dependent on change detection

reaction times to recognized word dependent on change detection

Figure 29. Left side: Word recognition rates (in percent) to the different word origin conditions with standard errors as error bars. Right side: Reaction times to recognized words from the different origin conditions (in ms) with standard errors as error bars.

It is possible that the detection of the change influenced the representation of the pre- and/or post-change image. Hence, the ANOVAs for recognition rates and reaction times were again done with the additional factor change detection (change detection vs. change blindness, see figure 29). The ANOVA considering change detection performance in the recognition rates did neither show a main effect of change detection on recognition rates ($F < 1$) nor an interaction of origin and change detection (F (2, 32) = 2.89, $p = 0.091$, $\eta_p^2 = 0.153$). The ANOVA for the reaction times did show an interaction between origin and change detection (F (1, 16) = 13.92, $p = 0.002$, $\eta_p^2 = 0.465$) but no main effect of change detection on the reaction times (F (1, 16) = 2.63, $p = 0.124$, $\eta_p^2 = 0.141$).

Q 4: Do the pre- and/or post-change items elicit the N4 priming effect?

ERP Data (figure 30):

As stated in the method section only not explicitly recognized trials when participants were change blind in the detection task are analysed. Grand-averages for the different origins of the word show a pronounced reduction in reaction to the post-change items in the N4 time interval most profound at centro-parietal and occipital leads. The repeated measures ANOVA for the N4 time interval (350-650 ms) resulted in a main effect for origin (F (2, 32) = 3.63, $p = .041$, $\eta_p^2 = 0.185$), caudality (F (2, 32) = 57.47, $p < .001$, $\eta_p^2 = 0.782$), and laterality (F (2, 32) = 10.83, $p = .001$, $\eta_p^2 = 0.404$). Post-change items elicited a significant reduction in the N4 component in comparison to new items (t (16) = 2.45, $p = 0.026$) and a marginal not significant reduction in comparison to the pre-change item (t (16) = -2.01, $p = 0.062$). In none of the post-hoc tests reported here did the pre-change and new items differ significantly. No other significant effects or interactions could be found in the ANOVA for origin*caudality (F (4, 64) = 2.08, $p = .139$, $\eta_p^2 = 0.115$), origin*caudality*laterality (F (2, 32) = 1.29, $p = .289$, $\eta_p^2 = 0.075$) or any other effects or interactions (Fs < 1).

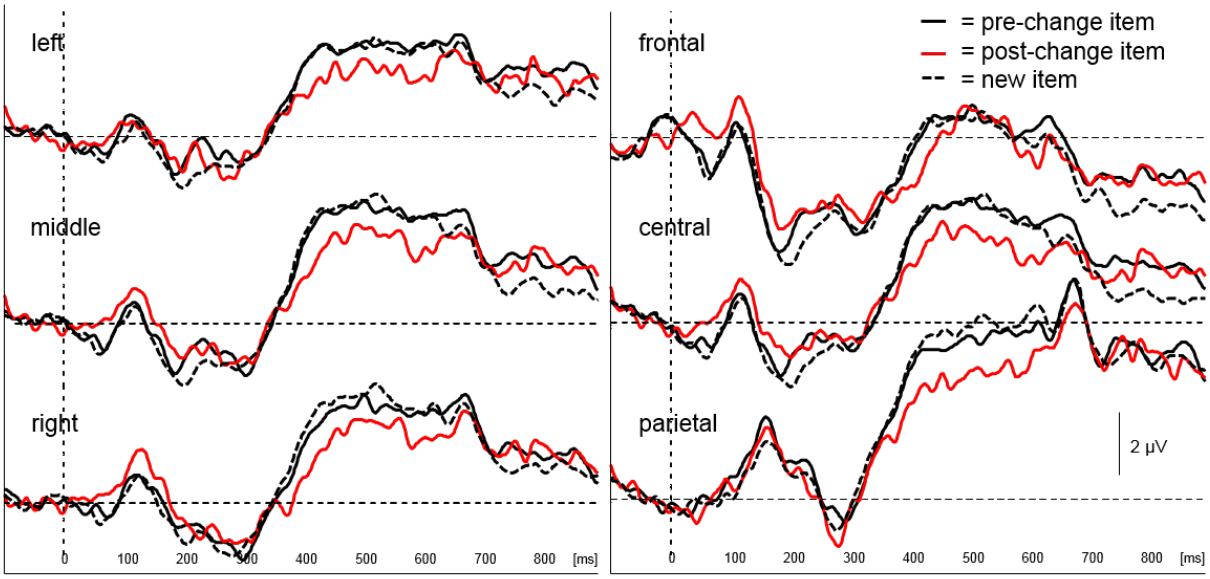


Figure 30. Left side: Grand averages for the origin of word at left (upper row), middle (middle row) and right (lower row) electrodes. Right side: Grand averages for the origin of word at frontal (upper row), central (middle row) and parietal (lower row) electrodes. Continuous lines are reactions to pre-change items, red continuous lines to post-change items and dashed lines to new items.

Discussion

Summary

The behavioural analyses done to reveal the predominance of either the perceptual or the semantic exogenous cue show that change detection is affected by both, the degree of perceptual deviations and a categorical change. An interaction of both exogenous cue types was obtained for behavioural data. The ERP results show that the degree of a perceptual deviation affects early visual processing – as reflected in a reduction of the N1 and P1 amplitude induced by major perceptual changes. In the P3 range, a significant enhancement in amplitude was triggered by major perceptual changes. As for the semantic deviations, ERP effects were restricted to the time range of the N2pc. Here, a change in category not congruent with the pre-change item reduced the negative amplitude. The combination of behavioural and ERP results indicate that the processes activated by searching for perceptual or semantic mismatches might be independent on the processing but not on the output level. Furthermore, unspecific changes elicit increased N1 and P3 ipsilateral to the change irrespective of semantic or perceptual deviancy. This might reflect the effect of exogenous cueing on attention (Cavanaugh & Wurtz, 2004; Landman et al., 2003; Posner, 1980; Shiu & Pashler, 1994).

The repetition priming task revealed enhanced recognition rates with faster reaction times for the post-change items. This is also reflected in the ERP data with a reduced N4 in reaction to post-change items. This is in line with studies showing that cueing facilitates the stability of visual representations (Schmidt et al., 2002) as well as the literature on overwriting (M. R. Beck & Levin, 2003; Brawn et al., 1999; Busch, 2013; Landman et al., 2003; Mitroff et al., 2004; Rensink, 2000; Simons, 2000).

Behavioural effects of perceptual and semantic exogenous cues in visual search

In the present experiment major perceptual deviants clearly lead to higher detection rates than minor perceptual deviants. This result is in line with the notion that perceptual salience triggers the guidance of visual-spatial attention. Correspondingly, perceptual deviants with a high salience were found to be detected faster and more correctly (Pringle et al., 2001). Major perceptual deviants do not have a higher salience according to the surrounding items but only to the pre-change item. In order to explain the higher detection rates of major perceptual mismatches one has to assume that the basic visual features of the first image are stored (luminance, extension of the single elements, etc.). The second image is compared to the first one with respect to these features, and local mismatch signals between the images are used to guide attention. This result also counters hypothesis stating that only the pre- or post-change image is stored (first impression and overwriting, see Simons, 2000).

Beside of the effect of perceptual salience, however, an effect of categorical change was also obtained: The detection rate was increased if the local item did not match – any longer – the categorical relationship of the objects presented. This kind of global processing confirmed earlier findings on the detection of semantic deviants in change blindness (Hollingworth & Henderson, 2000). Hollingworth and Henderson (2000) manipulated the semantic informativeness of a change object in relation to the context and found that a change object semantically inconsistent with the scene was detected more accurately and faster than objects semantically consistent with the scene. The detection of semantic deviants therefore depends on the context of the scene. The detection of the global mismatch requires the rapid analysis of the categorical relationship between the single items. Two processes for change detection are possible. First, the pre-change scene is categorized and compared to the post-change scene with the major semantic deviant. Second, the mismatch between the category of the post-change item and the category of the surrounding items in the second scene alone is sufficient to detect the deviant. Which process is responsible for the results found here can only be answered by a follow-up experiment. This was done with a reverse of the original and modified scene in Experiment 4. Therefore, the first scene contained the perceptual or semantic mismatch to the categorical homogenous second scene. In this way the second image does not contain a semantic deviant and it is impossible to detect the change without comparison of the two images. If the fourth experiment therefore shows the same detection rates/detection rate patterns it can be concluded that the comparison rather than the deviancy led to change detection.

Perceptual and semantic effects are obviously highly important in the guidance of visual attention and in this experiment they interact: Although all differences between minor and major deviances of one cue type are significant under either the minor or major deviant condition of the other cue type, this effect is less pronounced for the difference between minor and major semantic deviants when the perceptual deviant is minor. However, a predominant route cannot be identified. Despite of its higher effect size, the perceptual change did not differ significantly from the categorical mismatch (t (16) = 0.53, p = 0.605). These results are neither compatible with the finding that change detection was modulated primarily by the semantic consistency of the changed object (Stirk & Underwood, 2007), nor with the advantage of perceptual object features for change detection (Pringle et al., 2001). Comparing both effects, the ERP results will be helpful.

ERP effects induced by local mismatch signals (perceptual)

The effect on the P1 and N1 amplitudes is in line with previous findings: The components evoked by the perceptual deviances are said to reflect sensory analysis and visual discrimination processes for the P1 and the N1, respectively (Luck, Woodman, & Vogel, 2000). Mangun and Hillyard (1990) interpreted these two components as reflections of early sensory gating processes for attended stimuli (Eimer, 1993, p. 409). The sensory gating hypothesis is able to explain why minor perceptual changes increase the components as compared to major perceptual changes. Minor deviants are more difficult to detect and need more profound sensory gating than major deviants. Furthermore, Eimer (1993) reports that a reliable P1 is elicited only by difficult discriminations thereby supporting the interpretation of the results found here.

The N1 as a component reflecting a discrimination process is also elicited by stimuli in the focus of attention (Vogel & Luck, 2000). This discrimination process is more pronounced for higher perceptual loads in difficult discriminations e.g. the minor perceptual deviances. As stated above, the mismatch of the post-change item is only present in comparison with the pre-change item. The local mismatch arises through the comparison between the two scenes and draws attention to the location of the post-change item at which the item can be analysed and elicits a P1 and N1. This interpretation implicates that the first scene is stored for comparison.

That the perceptual attributes elicit an earlier ERP than the semantic attributes could be the reason for the difference shown in the detection rates. Earlier processing might enhance the possibility to detect the change before the presentation of the scene terminates. Earlier processing is potentially followed by more processing steps than later processing and hence heightens the possibility for detection and the formation of awareness. This assumption is supported by the results concerning the P3 time interval (300-500 ms). The P300 is said to be modulated by phenomenal awareness or detection, respectively (Koivisto et al., 2009; Koivisto & Revonsuo, 2003; Niedeggen et al., 2001). The amplitude of the P300 is increased by awareness (Aru & Bachmann, 2009) and detection (Niedeggen et al., 2001) as it is in the present experiment by major perceptual changes which have much higher detection rates than minor changes. Therefore the P3 might be an expression of enhanced detection as a result of the slightly prolonged processing time for perceptual deviants due to their earlier processing as indicated by the modulation of the P1 and N1. Nevertheless the time between P1/N1 and N2pc (found to be modulated by semantic deviancy) is extremely short and the advantage of earlier processing of perceptual attributes might be relatively small. However, this assumed advantage might be expressed in the higher effect size of perceptual deviances in the analyses for the change detection rates.

In sum, it is likely to assume that the modulation of the P1 and N1 - as expressions of a gating process for attended stimuli (Eimer, 1993) – indicates that attention is directed to a local mismatch signal in two succeeding images. In this line, the P1 and N1 also indicate that a stable internal representation of the first visual image has been built. The major physical deviance between the images triggers not only a modulation of early sensory processing, but is also more likely to be updated in working memory resulting in increased detection and/or awareness (P300 effect). This corresponds with the frequent detection of major physical mismatch signals observed in the behavioural data.

ERP effects induced by global deviations (semantic)

The analysis for the time interval 150-180 ms showed a main effect of semantic similarity in the time range of the N2pc. Surprisingly, no lateralization effect was obtained. The N2pc is known to show attentional shifts to the change object contralateral to the change (Schankin & Wascher, 2007, 2008). Therefore it is necessary to re-evaluate the assumption that the results found in the 150-180 ms time interval refers to the N2pc.

The effect on the time range is probably not due to a modulation of the N2b (found for deviants in active odd-ball experiments; Simson, Vaughan, & Ritter, 1977), or N2pb (sensitive to the probability of stimuli; Luck & Hillyard, 1994). Both components should also respond to perceptual deviations, and appear to depend on the probability of the events. It is more likely that the effect is related to an N170-effect - as observed by Scott, Tanaka, Sheinberg, and Curran (2008) in a category learning experiment. The negativity was elicited by perceptual categorization and increased with training. The authors assume that the N170 reflects familiarity of a category, and can therefore be enhanced by continued exposure to this category. It can be assumed that a similar process takes place in the third experiment: The changes within the same category enhance the negativity due to the increasing familiarity with this category which participants can form between the presentation of the pre-change and post-change scene as well as throughout the experiment. The enhancement of the N170 might therefore be another point in favour of the assumption that both scenes are compared.

Finally, it is important to note that the P300 effect is not obtained for categorical changes. This is in line with the finding that the N170 - as a correlate of categorization processes - is not a sufficient prerequisite for conscious detection (Scott et al., 2008). As compared to the processing of major physical deviances, the covert categorization process is also less likely to support the localization of the change. This is expressed in the lack of a P300 modulation, and in a reduced change detection rate.

It is clear from the results of the behavioural data that perceptual and semantic exogenous cues do interact. This, however, is not found in the ERPs. Electrophysiological data shows a clear separation in processing between perceptual and semantic cues. The different time course of processing with earlier components elicited by perceptual cues (P1 and N1) than by the semantic cues (N170) might hint at the hierarchy of processing in line with the classical view reviewed above (Hubel & Wiesel, 1968). Nevertheless, the time span between the P1/N1 and N170 is extremely short and given relevance of both feature dimensions for the task the reversed hierarchy hypothesis (Hochstein & Ahissar, 2002) cannot be ruled out. In the present experiment both perceptual and semantic attributes contribute to change detection and therefore the “vision at a glance” and the “vision with scrutiny” have to be active in parallel (Hochstein & Ahissar, 2002). It might very well be that both routes of processing are expressed in separate ERP components although their effects add in behavioural indices of visual search. It might be that separate routes of processing stimuli features are expressed in the ERP components that interact on the output level rather than the processing level. It is important to note that both stimuli features are interwoven. The semantic deviants are always in 50% major and in 50% minor perceptual deviants and the other way around. Nevertheless the factors perceptual and semantic deviancy are independent on the electrophysiological level. Both stimuli features seem to be processed on different pathways in spite of their entwining.

ERP effect induced by unspecific changes

As stated above the N1 found in the present experiment is enhanced over ipsilateral electrodes irrespective of the deviant condition. The enhancement of the N1 might be due to the exogenously cued change itself. The change is cued in three third of the trials by either perceptual or semantic major deviants. This cueing is always valid because the change item is the exogenous cue. Thus the exogenously cued change seems to capture attention as was proposed in the literature (Scholl, 2000). This result is in line with studies from Eimer (1993) and Mangun and Hillyard (1991) who also found ipsilateral enhanced effects for the N1 for validly cued items. The same effect was seen in the P3 time range. The P3 is also enhanced ipsilateral to the change irrespective of deviant condition. This lateralisation for exogenously cued changes is in line with results showing that attended targets elicit higher P3 amplitudes ipsilateral to the target in the visual (Hillyard & Münte, 1984; Skrandies, 1983) as well as the somatosensory P300 component (Bruyant, Garcialarrea, & Mauguiere, 1993; Josiassen, Shagass, Roemer, Ercegovac, & Straumanis, 1982). Thus the modulation of the N1 and P3 for cued changes irrespective of the deviant condition (perceptual or semantic variation of major and minor deviancy) is in line with two interpretations. First, the change itself captures attention as a local mismatch signal to a stored representation of the pre-change scene (Niedeggen et al., 2001). Second, the deviant stimuli embedded in the stimulus display are able to exogenously capture attention to the change position. The first explanation is only partly supported by the literature. As reviewed in the introduction ERP components are differently modulated by change detection and change blindness. The only component found for change blind trials and detected changes is the P3 or more generally a positive shift in the time range between 200 and 600ms (Fernandez-Duque et al., 2003; Niedeggen et al., 2001). Thus the ipsilateral P3 in reaction to unspecific changes might be a detector of local mismatches as stated above. The ipsilaterally enhanced N1 however does not support this explanation. The N1 is found for detected changes but not under change blindness (see introduction). The N1 is enhanced for attended stimuli and therefore associated with change detection (Fernandez-Duque et al., 2003; Koivisto & Revonsuo, 2003). The same association to attention is shown in the literature on the ipsilateral enhanced P3 (Hillyard & Münte, 1984; Skrandies, 1983). Thus it might be more parsimonious to assume that the exogenous cue captured attention and this is reflected in the enhancement of the N1 and P3 ipsilateral to the change. Nevertheless it cannot be ruled out that the detection of the local mismatch signal evoked by the change as compared to the pre-change representation allocates attention and thus elicits the two components.

Behavioural effects indicating the formation of stable visual representations

The post-change item shows a stable representation as indicated by the highest recognition rates and faster reaction times as compared to the pre-change item and a new item. Different explanations are possible for the facilitated storage of the post-change item. The enhanced processing of deviant stimuli should also influence the storage of information with privileged storage for salient/deviant items (Todd & Marois, 2004) and thereby interfering with the maintenance of the pre-change representation. Another explanation might be retrieval blockage as introduced by Yeh and Yang (2009). They argue that the representation of the post-change item blocks the availability of the pre-change item for retrieval. Additionally the experimental procedure might add to the found results. Representations stored in the visual short-term memory have to be actively maintained (Vogel et al., 2006). With every new representation the maintenance of already represented objects/scenes gets more difficult because of the limited storage capacity of visual short-term memory (Cowan, 2001). The representation of the post-change scene might supersede the previously stored representation of the pre-change scene (Luck & Hollingworth, 2008). The time between the presentation of the pre-change scene and the recognition task is longer than between the post-change scene and the recognition task. The maintenance of the pre-change representation should therefore require more resources than the maintenance of the post-change resulting in lower recognition rates (Luck & Hollingworth, 2008).

Despite all these processes favouring the post-change item, it is clear from the results that the pre-change item is represented. The repetition priming task, therefore, also supports the assumption that the first scene is stored for comparison (Busch, 2013). Although post-change items show highest recognition rates and lowest reaction times the pre-change items are better recognized than new items as was the case in the experiment by Busch (2013). This shows that the pre-change scene is stored. The reduced recognition rates for pre-change items could be a result of the deviancy of items in the post-change scene. As was shown above, the perceptual and semantic deviancy of the post-change item influences the processing on the behavioural and electrophysiological level. And as stated above this facilitating effect for deviants in the post-change scene might have interfered with the retrieval or storage of the post-change item representation.

When the recognition rates and reaction times are re-analysed considering change detection it is revealed that change detection slows down the reaction to pre-change items. This might be a result in favour of the retrieval blockage hypothesis (Yeh & Yang, 2009). It seems to take more time to decide if the pre-change item was presented when the change was detected. However this effect can only be found for reaction times but not for the recognition rates where no effect of change detection could be found. Nevertheless a not significant trend can be seen in the graph that shows decreased recognition rates under change detection again in line with the retrieval blockage hypothesis.

The result that recognition rates are not modulated by change detection is quite astounding. One would assume that change detection should lead to increased recognition rates at least for the post-change item. The inspection of the visual data shows a not significant enhancement of recognition rates if the change was detected. The lack of an increase under change detection might be due to the fact that the categories are constructed from a finite number of single stimuli. Thus the stimuli are used repeatedly in different configurations. This should generally have complicated the recognition of the items in a certain trial because of repeated presentation of the single items. Participants might be unsure if the item was presented in the present or previous trials. Therefore it can be assumed that the change detection could not profoundly increase recognition rates of the post-change item due to a ceiling effect.

ERP effects reflecting visual representations

The ERP component N400 reflects lexical semantic processing (Dunn, Dunn, Languis, & Andrews, 1998; Kutas & Hillyard, 1989) and long- or short-term memory search (Picton, 1988; Stelmack & Miles, 1990). Stelmack and Miles (1990) showed that the N4 is reduced by repetition priming with a picture priming the related word. The results found here clearly replicate this finding with an attenuation of the N4 in reaction to the post-change item. Therefore the ERP data reflects the behavioural data with an increased processing for the post-change item. As was argued above the deviancy of changed items as the exogenous cue in the post-change scene might serve to facilitate processing of the post-change scene and therefore enhance priming.

The behavioural and electrophysiological results for the repetition priming task found here are in line with two explanations. First, the presence of exogenous cues in the post-change scene facilitates the processing of that scene leading to higher recognition rates and facilitated repetition priming. Second, short-term memory processes might benefit the recall/recognition of the post-change scene again leading to higher recognition rates and facilitated repetition priming. The following experiment should shed light on the plausibility of these two explanations.

The third experiment clearly shows that semantic as well as perceptual exogenous cues influence visual search. The exogenous cue itself is able to capture attention to the change position as expressed in an unspecific change effect in the ERP data. Both cue features advance visual search expressed in enhanced change detection for perceptual and semantic deviants and electrophysiological markers. Furthermore the presentation of these exogenous cues also influenced the stability of representations of the scenes with an advantage for the scene containing the cue. As mentioned repeatedly above, the results (at least of the perceptual deviant condition) are in line with the assumption that the pre-change scene is analysed and stored for comparison with the post-change scene and change detection. For the semantic deviants it is theoretically possible that a change is detected through the deviancy of the post-change item to the surrounding categorised items without a comparison to the pre-change item. The first scene might be categorised and the post-change item of a different category serves as the change detection signal. To test this assumption the fourth experiment was done in which the deviant is presented in the pre-change scene.

Experiment four

Reversal of experiment three

The fourth experiment is again done to compare the influence of semantic and perceptual stimuli features on visual search but with the addition of testing the assumption that the results obtained in the third experiment are based on the storage of the pre-change scene and the comparison *between* the stored memory trace of pre- and post-change scene rather than the detection of the exogenous cues in the comparison *within* the post-change scene. To test this, the fourth experiment is reversed in respect to the fact that the exogenous cues (perceptual or semantic deviants) are now presented first in the pre-change scene and the semantically homogenous scene is presented as the post-change scene. Thus the third and fourth experiments are a parallel to the first two experiments with respect to the change of cue position between pre- and post-change scene.

Perceptual deviancy can only be effective through the comparison between pre- and post-change scene. The present experiment thus should be a replication of the previous experiment for the perceptual deviants. As argued above the comparison within the post-change scene, however, could have been done in the semantic major deviant condition where the exogenous cue poses a mismatch to the common category of the other five items. Therefore the question is:

Q 1: Are semantic changes detected through comparison between pre- and post-change representations?

According to the results of the perceptual exogenous cues it is likely that change detection takes place through comparison between the scenes for the semantic exogenous cues as well. The semantic exogenous cue is deviant to the pre-change item as well as to the other items in the post-change scene. Both cue forms interact in their influence on the behavioural expression of change detection and they therefore might rely on the same comparison process. If change detection cued by semantic deviants also relies on the comparison between the scenes, it can be hypothesized that:

H 1: Semantic deviancy does not elicit differentiated responses in the researched electrophysiological components in the pre-change scene itself.

The influence of cue position on the cueing effect in visual search

In the first two experiments it could be seen that the facilitating effect of explicitly processed exogenous cues is modulated by the position of the cue in the pre- or post-change scene. This could be explained with the relevance the cue has for change detection if it is presented before or after the change is done. The exogenous cues used in the third experiment are presented in the post-change scene and pose a deviant to the semantic standard formed in the pre-change scene. If the deviant is presented in the pre-change scene no semantic standard can be previously formed. Hence the question is:

Q 2: Does the reversal of exogenous cue position influences the facilitating cueing effect on change blindness?

Nevertheless as was explained in the third experiment, the perceptual exogenous cue is deviant to the item formerly presented at its position rather than the perceptual context in the post-change scene. Therefore it can be hypothesized that:

H 2a: Perceptual deviancy again facilitates change detection and leads to faster reaction times.

It is unclear if this is also true for the semantic exogenous cues. As stated above it might be the facilitating effect of semantic deviancy is due to comparison between pre- and post-change item or the comparison between scene context and the deviant item within this scene. If semantic exogenous cues operate through comparison between scenes as perceptual exogenous cues the detection of changes should again be facilitated. On the other hand, if they operate on the comparison between category items and semantic deviant within the scene, the categorical homogenous post-change scene should not facilitate change detection. Nevertheless as explained above, perceptual and semantic exogenous cues interact on the behavioural expression of change detection. This might be a sign that they rely on similar processes (comparison between pre- and post-change scene) and it thus can be hypothesized that:

H 2b: Semantic deviancy enhances change detection and speeds up reaction times.

In the third experiment perceptual and semantic exogenous cues interacted in their effect on change detection performance. Although the difference between minor and major semantic deviants is less pronounced if perceptual deviants are minor it is still significant as are all other differences. The variation of perceptual deviancy shows higher effect sizes but does not differ significantly from variations of semantic deviancy. Therefore the question is:

Q 3: Does the reversal of exogenous cue position influences the interaction of semantic and perceptual deviancy on change detection performance?

It was argued that the “vision at a glance” and the “vision with scrutiny” are active in parallel because both routes are necessary to detect the change and interact on the output level (Hochstein & Ahissar, 2002). This interaction should not be dependent on the cue position if the facilitating effect of these exogenous cue types is effective through pre- and post-change item comparison enabled by attentional capture. Thus it can be hypothesized, that:

H 3: Semantic and perceptual exogenous cues interact in their facilitating effect on change detection performance.

Regardless of the behavioural interaction of semantic and perceptual exogenous cues, they independently modulated the electrophysiological components. This might hint at different processing routes for semantic and perceptual stimulus features or at different levels in the information processing hierarchies (Hochstein & Ahissar, 2002; Hubel & Wiesel, 1968). On the other hand the differentiated ERP responses induced by semantic and perceptual cues might reflect independence only on the processing level but the effects of these different processes afterwards interact on the output level. The question here is:

Q 4: Does the change of exogenous cue position influence the independence of ERP responses to semantic and perceptual cue features?

The interaction on the output level might be due to the common categorical standard formed in the pre-change scene of the third experiment. The reversal of deviant position and semantic homogenous scene therefore should not influence the processing levels. This should at least be true for the perceptual deviancy condition. As assumed above, the perceptual deviant is only effective in the comparison between pre- and post-change item. Therefore the pattern of results from the previous experiment concerning perceptual deviancy should be replicated:

H 4a: ERP responses in reaction to the post-change scene induced by perceptual exogenous cues should replicate the results from the third experiment with a decrease of the P1 and N1 as well as an increase of the P3 by major deviances.

It is unclear so far if semantic deviances in the third experiment are effective through their deviancy to the pre-change item or to the remaining items in the post-change scene. The semantic deviancy of the exogenous cue modulated the N170 with an enhancement by changes within a category. This is due to the fact that the N170 is increased by familiarity with a category, which is higher for changes within a category where the global category remains intact. This ERP component thus might be elicited in the post-change scene by the presentation of the homogenous category irrespective of the deviancy of the semantic exogenous cue in the pre-change scene. If a comparison between pre- and post-change item is the mechanism for change detection in the semantic deviancy condition the semantic deviant in the pre-change scene might capture attention and thus an attentional shift might be detectable after onset of the post-change scene reflected in an N2pc (Schankin & Wascher, 2007, 2008). If on the other hand the effect of semantic deviancy of the third experiment is due to comparison within the scene no differentiated processing according to the deviancy of the exogenous semantic cue in the pre-change scene should be seen in the post-change scene. Hence two alternative hypotheses can be made:

H 4b-1: If pre- and post-change item are compared in the semantic deviant condition the reversal of exogenous cue position should not affect the ERP responses in reaction to the post-change scene and replicate the increase of the N170 by changes within category.

H 4b-2: If the deviant is compared within its scene no differentiated ERP responses in reaction to the post-change scene should be found according to semantic deviancy in the pre-change scene.

The influence of cue position on the stability of scene representation

The reversal of original and modified scene might also influence the stability of representations. As argued above, the advantage of the post-change item in recognition could be due to the influence of the exogenous cue for processing or short-term memory processes. Therefore the question is:

Q 5: Does the change of cue position influence the formation of stable visual representations?

If the presence of cues or deviants in a scene facilitates processing (Schmidt et al., 2002; Todd & Marois, 2004) repetition priming of the *pre-change* item should lead to higher recognition rates of and faster reaction times to the pre-change item and show differentiated processing in the electrophysiological data in reaction to repetition priming of the pre-change item. If, on the other hand, short-term memory processes and retrieval blockage (Luck & Hollingworth, 2008; Yang & Yeh, 2009) are responsible for the obtained results in experiment three, the results should be similar with enhanced recognition and faster reaction times of *post-change* items and replicated the ERP responses obtained in experiment three. It is likely that the cueing effect on the stability of representations and short-term memory processes and retrieval blockage had an additive effect in the third experiment where these processes enhance the stability of post-change item representations. Yang and Yeh (2009) stated that retrieval blockage could be solved by cueing the pre-change item. Therefore this effect should not be present in the fourth experiment. In the current experiment the cueing effect and short-term memory processes should enhance the stability of different representations. Cueing should facilitate the pre-change item representation whereas short-term memory processes should facilitate the post-change item representation. Therefore it can be hypothesized that:

H 5: Cue position enhances the repetition priming effect of the pre-change item as well as the post-change item with higher recognition rates and faster reaction times.

Q 6: Does the change of cue position influence the N4 priming effect?

In the third experiment, it could be seen that the N4 priming effect reflected the behavioural priming effect. Thus it can be hypothesized that the proposed effect of cueing for the pre-change item representation and short-term memory processes active on the post-change item representation in the behavioural data are again reflected in the N4 priming effect:

H 6: The pre- and post-change items show a N4 repetition priming effect.

It is nevertheless not clear if one process is more effective on the formation of stable representations than the other. If repetition priming is stronger for cueing or short-term memory processes this might shed light on the question to which degree these processes are active on the formation of stable representations. The present experiment could therefore shed light on the question if both scenes in a change blindness paradigm are stored and what determines the recognition of items from the pre- or post-change scene (deviant/cue effects on visual memory vs. short-term memory processes).

Method and Material

Participants

EEG and behavioural data from 24 subjects were recorded. Four participants had to be excluded from the analyses due to a too low number of trials for analyses. This was due to too many artefacts in the EEG data and/or too many errors in the behavioural data. The analysed data set included 19 right-handed participants and one left-handed subject (12 female, 8 male; aged between 18 and 46; mean age: 24.7) with German mother tongue, and normal or corrected-to-normal vision.

Stimuli and experimental design and procedure

Stimuli, setting, procedure and experimental variables were the same as in the third experiment with the single exception that the original and changed scene of the third experiment were reversed resulting in the presentation of the deviance in the first scene.

EEG data recording and analysis

EEG was recorded and analysed as in the third experiment. For each participant and each electrode, artefact-free trials were averaged according to the pre-change, the post-change image, and the target word. The pre-change images were averaged according to categorized and unsorted images. The post-change images were averaged according to the four combinations of perceptual and categorical similarity between pre- and post-change item. The target word images were averaged according to their relation to the original scene, the changed scene or an unrelated scene. Grand-averaged ERP potentials were used to define the temporal segments reflecting separate ERP components (P1: 80-110 ms, N1: 120-150 ms, P2: 200-230 ms, P3: 300-500 ms, N4: 250-310/350-650 ms). The analysis of the components P1, N1, P2, and P3 were again focused on the posterior electrodes (electrode pairs at parietal (P), temporo-parietal (PT), occipital (O) leads).

Experimental variables

The same behavioural and electrophysiological dependent and independent variables were analysed in the same way as in the first experiment with the addition of the analyses concerning the pre-change scene. Here dependent variables are the ERP potentials and the independent variables are semantic homogeneity, electrodes and hemisphere (ipsilateral vs. contralateral) resulting in a three-factorial repeated measurement design. Results of change detection rates and detection reaction times as well as recognition rates and recognition reaction times are afterwards compared with the ones of the third experiment through the additional between subjects factor ‘experiment’ (3 vs. 4).

Results

Q 1: Are semantic changes detected through comparison between pre- and post-change representations?

ERP Data – pre-change image (figure 31):

The variation in perceptual similarity is achieved by the comparison between pre- and post-change object and can therefore not be found in relation to the other images in the scene itself whereas the between category deviant can be detected in the scene itself due to the difference in category to the other images. Therefore only the semantic similarity is analysed in the pre-change scene.

Grand-averages for semantic deviants in the pre-change image show an enhancement for between category changes contralateral to the change in the 120-220 ms time interval. Contrary to the expectations following the visual inspection of the grand averages, no significant effect of or significant interaction with semantic homogeneity could be found at any time interval.

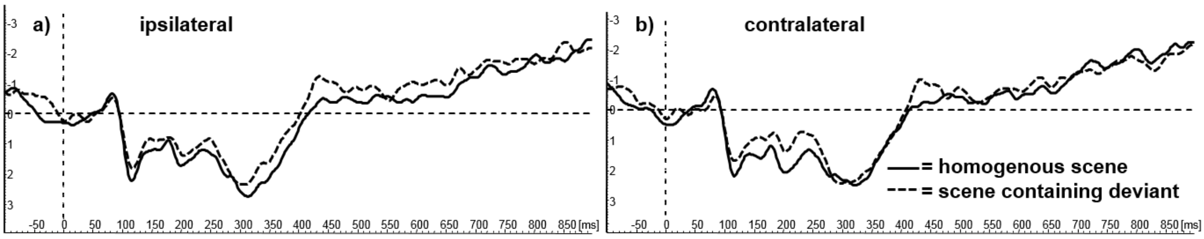


Figure 31. Grand averages for the effect of semantic homogeneity at the ipsilateral (a) and contralateral (b) parietal electrode for the pre-change image. Continuous lines are homogenous categories; dashed lines are categories with one categorical deviant.

Q 2: Does exogenous cue position influence the facilitating cueing effect on change blindness?

Behavioural Data (figure 32):

In the fourth experiment, participants detected the change between the images in about 46-66 % of the trials depending on the variation of perceptual and semantic similarity. Figure 32 shows increased detection rates for major as compared to minor perceptual deviance as well as for changes between categories. The repeated measures analysis of variance (ANOVA) showed main effects of perceptual similarity (F (1, 19) = 34.05, $p < 0.001$, $\eta_p^2 = 0.642$) as well as of semantic similarity (F (1, 19) = 10.58, $p = 0.004$, $\eta_p^2 = 0.358$). No interaction between the experimental factors was obtained (F (1, 19) = 0.007, $p = 0.933$, $\eta_p^2 = 0.000$).

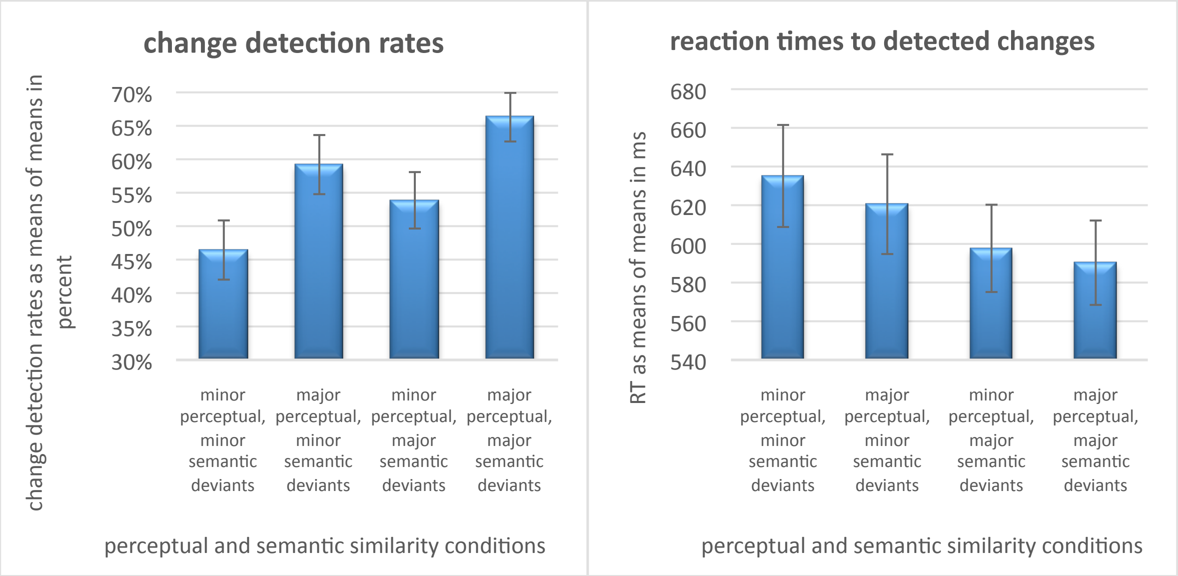


Figure 32. Left side: Change detection rates (in percent) for the four experimental conditions with standard errors as error bars. Right side: Reaction times to detected changes (in ms) for the four experimental conditions with standard errors as error bars.

The repeated measures ANOVA for the reaction times showed only a main effect of semantic similarity (F (1, 19) = 4.45, $p = 0.048$, $\eta_p^2 = 0.190$) with significantly lower reaction times to between category changes. None of the other effects reached significance (*F*s < 1).

To compare the third and fourth experiment, ‘experiment’ was introduced as a between subjects factor and the ANOVAs for detection rates and reaction times were repeated with this additional factor. No interaction with the factor experiment could be found (*F*s < 1).

Q 3: Does the change of exogenous cue position influence the independence of ERP responses to semantic and perceptual cue features?

ERP Data – post-change image (figure 33):

Grand-averages for perceptual and semantic deviants do not show a difference between major and minor deviants (either perceptual or semantic) for the P1, N1 or N2pc time range as analysed in the third experiment. In the P3 time range major perceptual deviants and within category changes elicit an enhancement.

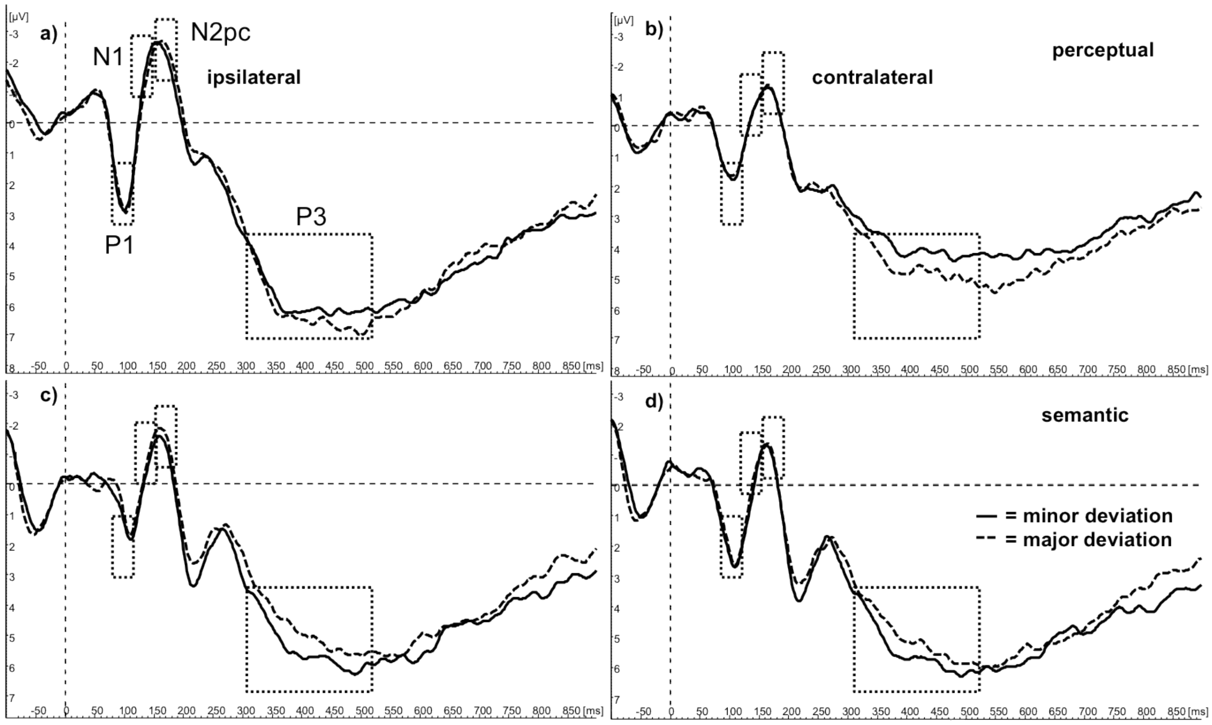


Figure 33. Grand averages for the effect of perceptual similarity between pre- and post-change item at temporo-parietal electrodes (upper row, a and b) and semantic similarity

between pre- and post-change item at occipital electrodes (lower row, c and d) at the ipsilateral (left side, a and c) and contralateral (left side, b and d) side for the post-change image. Continuous lines are minor perceptual deviants/same category; dashed lines are major perceptual deviants/different category. Dashed frames highlight the time segments for the ERP components P1, N1, N2pc, and P3.

The repeated measures analysis of variance (ANOVA) for the P1 time interval (80-110 ms) revealed no significant main effects except electrode (*F* (2, 38) = 4.68, $p = .025$, $\eta_p^2 = 0.198$) and the interaction of hemisphere and electrode (*F* (2, 38) = 9.73, $p = .003$, $\eta_p^2 = 0.339$). The interaction is due to an enhancement of the P1 contralateral to the change at occipital leads (*t* (19) = 2.7, $p = 0.014$). No further significant effects or interactions could be revealed for perceptual similarity*electrode*laterality (*F* (2, 38) = 1.67, $p = .203$, $\eta_p^2 = 0.081$), semantic*perceptual similarity (*F* (1, 19) = 1.76, $p = .200$, $\eta_p^2 = 0.085$), semantic*perceptual similarity*electrode (*F* (2, 38) = 2.28, $p = .122$, $\eta_p^2 = 0.107$), or any of the other effects or interactions (*F*s < 1).

The repeated measures ANOVA in the N1 time range (120-150 ms) revealed a significant interaction for perceptual similarity*semantic similarity*electrode*hemisphere (*F* (2, 38) = 3.64, $p = .047$, $\eta_p^2 = 0.161$) and main effects for electrode (*F* (2, 38) = 12.53, $p < .001$, $\eta_p^2 = 0.397$) and hemisphere (*F* (1, 19) = 6.95, $p = .016$, $\eta_p^2 = 0.268$). The interaction is due to a not significant trend for an increase of the N1 for minor perceptual deviants at temporo-parietal leads ipsilateral to the change (*F* (1, 19) = 3.98, $p = .061$, $\eta_p^2 = 0.173$). Again an unspecific change effect was found in an increase of the N1 ipsilateral to the change. No other significant effects or interactions were revealed for perceptual similarity (*F* (1, 19) = 1.23, $p = .281$, $\eta_p^2 = 0.061$), electrode*laterality (*F* (2, 38) = 1.32, $p = .279$, $\eta_p^2 = 0.065$), semantic similarity*electrode*laterality (*F* (2, 38) = 1.6, $p = .218$, $\eta_p^2 = 0.078$), perceptual similarity*laterality (*F* (1, 19) = 1.46, *p* = .242, η_p^2 = 0.071), perceptual similarity*electrode*laterality (*F* (2, 38) = 2.44, *p* = .114, η_p^2 = 0.114), semantic*perceptual similarity (*F* (1, 19) = 1.89, *p* = .186, η_p^2 = 0.090) or any other effects or interactions (*F*s < 1).

At the N2pc time interval (150-180 ms) no effect of semantic or perceptual similarity (*F*s < 1) could be found but a main effect of hemisphere (*F* (1, 19) = 6.41, *p* = .020, η_p^2 = 0.252) with higher amplitudes contralateral to the change. No further significant effects or interactions could be found for electrode*laterality (*F* (2, 38) = 2.08, *p* = .139, η_p^2 = 0.099), semantic similarity*laterality (*F* (1, 19) = 1.06, *p* = .317, η_p^2 = 0.053), semantic similarity*electrode*laterality (*F* (2, 38) = 1.1, *p* = .332, η_p^2 = 0.055), perceptual similarity*electrode (*F* (2, 38) = 2.6, *p* = .090, η_p^2 = 0.120), semantic*perceptual similarity (*F* (1, 19) = 1.65, *p* = .215, η_p^2 = 0.080), semantic*perceptual similarity*electrode (*F* (2, 38) = 1.0, *p* = .373, η_p^2 = 0.050) or any other effects or interactions (*F*s < 1).

The repeated measures ANOVA for the P3 time interval (300-500 ms) resulted in a significant interaction for perceptual*semantic similarity (*F* (1, 19) = 6.17, *p* = .022, η_p^2 = 0.245) and semantic similarity*electrode (*F* (2, 38) = 3.27, *p* = .049, η_p^2 = 0.147) as well as a main effect for hemisphere (*F* (1, 19) = 8.45, *p* = .009, η_p^2 = 0.308) and the interaction electrode*hemisphere (*F* (2, 38) = 7.63, *p* = .006, η_p^2 = 0.286). The perceptual*semantic similarity interaction is due to a marked difference for perceptual deviants in between category trials with an enhancement of the P3 amplitude for major perceptual deviants (*t* (19) = -3.61, *p* = 0.002) and a significant difference for semantic deviants under minor perceptual changes with an increase in P3 amplitude by within category changes. The interaction of semantic similarity and electrode is due to an enhancement of the P3 for changes within a category at occipital electrodes ipsilateral to the change (*F* (1, 19) = 5.16, *p* = .035, η_p^2 = 0.214). The unspecific change effect indicated by the hemisphere effect and hemisphere*electrode interaction shows an enhancement of the P3 ipsilateral to the change especially at parietal (*t* (19) = -3.62, $p = 0.002$) and parieto-occipital electrode pairs (*t* (19) = -2.77, $p = 0.012$).

No other significant effects or interactions could be found for electrode (*F* (2, 38) = 2.98, $p = .078$, $\eta_p^2 = 0.135$), semantic similarity (*F* (1, 19) = 1.53, $p = .231$, $\eta_p^2 = 0.075$), perceptual similarity (*F* (1, 19) = 2.29, $p = .147$, $\eta_p^2 = 0.108$), semantic similarity*electrode (*F* (2, 38) = 3.27, $p = .055$, $\eta_p^2 = 0.147$), semantic similarity*laterality (*F* (1, 19) = 1.82, $p = .193$, $\eta_p^2 = 0.087$), semantic similarity*electrode*laterality (*F* (2, 38) = 2.0, $p = .152$, $\eta_p^2 = 0.095$), semantic*perceptual similarity*laterality (*F* (1, 19) = 3.14, $p = .092$, $\eta_p^2 = 0.142$), semantic*perceptual similarity*electrode*laterality (*F* (2, 38) = 2.42, $p = .107$, $\eta_p^2 = 0.113$) or any other effects or interactions (*F*s < 1).

Q 4: Does the change of cue position influence the formation of stable visual representations?

Behavioural Data:

Participants recognized the word in 15.9 % of the trials in the new item condition, in 75.8 % of the pre-change condition and in 46.8 % of the post-change condition. The repeated measures ANOVA showed a significant main effect of origin of word (*F* (2, 38) = 121.81, $p < 0.001$, $\eta_p^2 = 0.865$). Post-hoc tests revealed significantly higher recognition rates for the pre-change item in comparison to the post-change (*t* (19) = 8.15, $p < 0.001$) and new item (*t* (19) = 13.21, $p < 0.001$) and also higher recognition rates for the post-change item as compared to the new item (*t* (19) = 9.34, $p < 0.001$).

As in the third experiment the reaction times are analysed only for the pre- and post-change item due to the extremely low number of (falsely) recognized new words. The repeated measures ANOVA for the reaction time data showed a significant main effect of origin of word (F (1, 19) = 55.36, $p < 0.001$, $\eta_p^2 = 0.744$) with much faster reaction times to pre-change items.

The ANOVAs for recognition rates and reaction times were repeated with the additional between subject factor experiment (3 vs. 4) and showed, unsurprisingly, significant interactions of the factor experiment with origin of word (recognition rates: F (2, 70) = 52.64, $p < 0.001$, $\eta_p^2 = 0.601$, reaction times: (F (2, 70) = 24.76, $p < 0.001$, $\eta_p^2 = 0.414$).

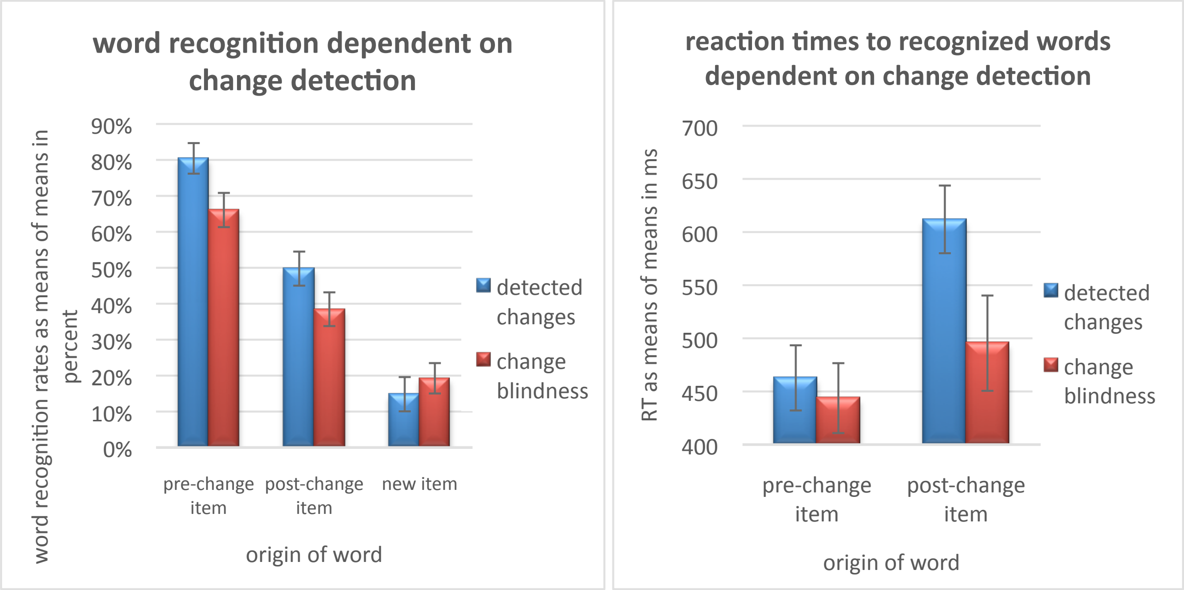


Figure 34. Left side: Word recognition rates (in percent) to the different word origin conditions with standard errors as error bars. Right side: Reaction times to recognized words from the different origin conditions (in ms) with standard errors as error bars.

And as in the third experiment the influence of change detection is analysed by including the factor change detection (change blindness vs. change detection, see figure 34) in the ANOVAs of recognition rates and reaction times. The ANOVA for the recognition rates revealed a main effect of change detection on recognition rates (F (1, 19) = 5.59, $p = 0.029$, $\eta_p^2 = 0.227$) with higher recognition rates under change detection as well as an interaction of change detection*origin of word (F (2, 38) = 12.71, $p < 0.001$, $\eta_p^2 = 0.401$).

Post-hoc tests showed that this interaction is due to significant higher recognition rates of words under change detection than change blindness for the pre-change item (*t* (19) = -3.19, *p* = 0.005) and for the post-change item (*t* (19) = -2.93, *p* = 0.009). The ANOVA for the reaction times showed a main effect of change detection on the reaction times to recognized words (*F* (1, 19) = 5.5, *p* = 0.030, η_p^2 = 0.224) but no interaction with origin of word (*F* (1, 19) = 3.33, *p* = 0.084, η_p^2 = 0.149). Interestingly participants were quicker to react to recognized words after change blindness.

Q 5: Does the change of cue position influence the N4 priming effect?

ERP Data (figure 35)

As in the third experiment the analyses for the word recognition task were done only for not-recognized words after change blindness, which do not require a motor response. Grand-averages for origin of word show a pronounced reduction in the N4 time interval at central and parietal leads.

The repeated measures ANOVA for the N4 time interval (350-650 ms) resulted in a main effect for origin (*F* (2, 38) = 6.21, *p* = .009, η_p^2 = 0.246), an interaction of origin and caudality (*F* (4, 76) = 7.31, *p* = .006, η_p^2 = 0.278) as well as main effects of caudality (*F* (2, 38) = 37.57, *p* < .001, η_p^2 = 0.664) and laterality (*F* (2, 38) = 9.48, *p* = .002, η_p^2 = 0.333). The pre-change item elicited a significant reduction in the N4 amplitude in comparison to the post-change (*t* (19) = 2.44, *p* = 0.025) and new item (*t* (19) = 2.86, *p* = 0.010) at central and parietal leads.

None of the remaining interactions in the ANOVA reached significance (origin*laterality: *F* (4, 76) = 2.77, *p* = .062, η_p^2 = 0.127, caudality*laterality: *F* (4, 76) = 2.53, *p* = .084, η_p^2 = 0.118, and origin*caudality*laterality: *F* (8, 152) = 2.4, *p* = .092, η_p^2 = 0.112).

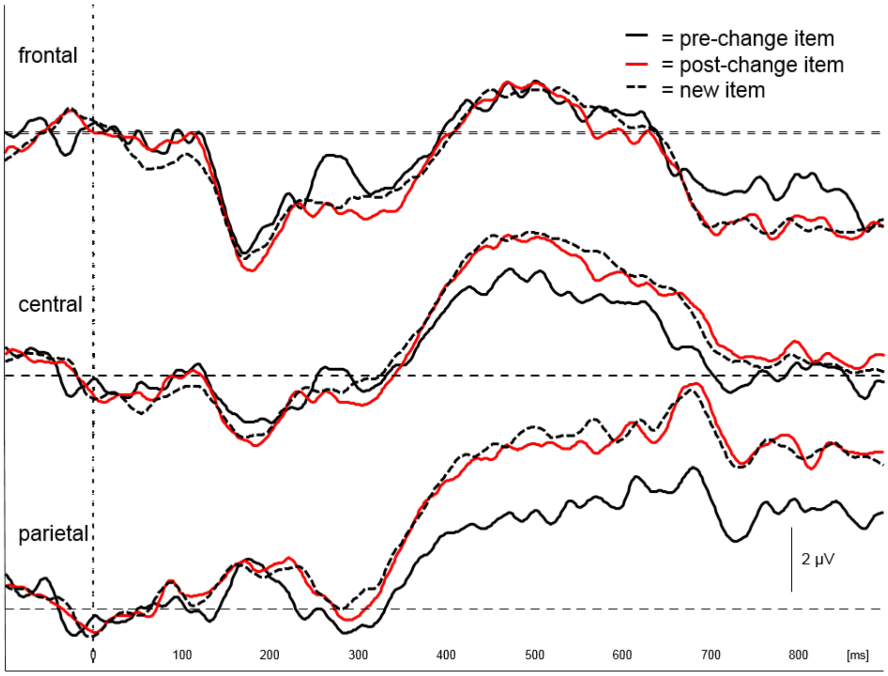


Figure 35. Grand averages for the origin of word at frontal (upper row), central (middle row) and parietal (lower row) electrodes. Continuous lines are reactions to pre-change items, red continuous lines to post-change items and dashed lines to new items.

Discussion

Summary

No effect of the semantic deviancy on the analysed ERP components could be found for the pre-change image itself hinting on a comparison mechanism between scenes rather than within the scene holding the semantic deviant.

The behavioural results show that both exogenous cue types, the degree of perceptual and semantic deviations, again affect change detection. However, in contrast to the previous experiment, no interaction of the perceptual and semantic deviants could be obtained for behavioural data. The difference in effect size with a higher effect for perceptual deviants is significant and shows an independence of both deviant types. Again in contrast to the previous experiment, the independence of both cue type effects is not clearly mirrored in the electrophysiological data. The ERP results for the post-change image show a not significant trend for an effect on early visual processing by the degree of a perceptual deviation – as reflected in a not significant increase of the N1 amplitude induced by minor perceptual changes. Semantic deviants affected ERP components in the P3 range. A significant enhancement in amplitude was triggered by within category changes. Nevertheless perceptual and semantic cue features additionally interact in their effect on the P3 component. With the exogenous cue presented in the pre-change scene the behavioural results show an independence of the perceptual and semantic stimulus features and in the ERP components mixed results are obtained.

As in the third experiment an unspecific change effect irrespective of the semantic and perceptual deviant conditions could be seen. This effect could be found contralateral to the change in the time ranges of the P1 and N2pc and, as in the third experiment, ipsilateral to the change in the N1 and P3 time range.

The repetition priming task shows an advantage of the pre-change items in recognition rates and reaction times. The replacement of deviants into the pre-change scene seems to facilitate the storage of that scene in line with Schmidt et al. (2002). The ERP data confirm this assumption with a reduction in amplitude of the N4.

The effect of exogenous semantic and perceptual cues on change blindness

The object of the fourth experiment was to replicate the findings of the third experiment and to ascertain that the comparison of the pre- and post-change image rather than the salience of the deviant leads to the detection. As in the third experiment, major deviants clearly led to higher detection rates than minor deviants for perceptual as well as semantic deviants. This effect was replicated although in the present experiment no deviant was present in the post-change image for which the change detection reaction was required. Thus the deviant captured attention in the pre-change image to the change position and promoted change detection. The repeated measures ANOVA with "experiment" as between subject factor revealed no significant interaction with “experiment”. This is an argument in favour of the assumption that it is the comparison of the pre- and post-change image and not the deviancy itself that leads to change detection.

In the third experiment the pre-change scene consisted of six images of the same category. This scene therefore could be seen as a standard, which is formed through categorization. The post-change scene meanwhile provided a deviant to this semantic standard regardless of its being perceptual or semantic. This may be an explanation for the interaction found in the previous experiment. The standard is a semantic category and it seems that not only the semantic but also the perceptual deviant is compared with the standard. Hence the detection of perceptual deviants is more pronounced if in conjunction with a between category change (major semantic change). In the fourth (reversed) experiment, however, the semantic standard cannot be formed in the pre-change scene that holds the deviant. Due to the fact that this standard is missing and semantic and perceptual deviants cannot be compared with the category standard, it is not surprising that no interaction between deviant types was found in the behavioural results of the fourth experiment. Both deviant types are not mediated by the categorical standard and thus act independently on the outcome level. At this point it is again important to bear in mind that semantic and perceptual deviancy is interwoven. There are no solely semantic or perceptual changes but always a mixture. Nevertheless both factors are independent on the behavioural level in the present experiment. This speaks for different processing pathways for both stimuli features as argued for the processing level in the previous experiment. In contrast in the present experiment the no previously formed categorical standard mediates the output of both pathways in the present experiment.

Effect size of perceptual similarity in the third experiment was higher than that of semantic similarity although not significant. In the present experiment effect size difference was significant. The major perceptual deviant as a local mismatch signal is equally salient in the comparison between pre- and post-change scene whereas the global mismatch signal (semantic similarity) cannot be equally salient when no global semantic category is previously formed. It seems that the categorical homogenous stimuli in the post-change scene are not treated as a semantic category standard with which to compare the semantic deviant from the pre-change scene. Thus the reversal of cue position from post- to pre-change image reduced the salience of semantic deviants. To detect the semantic deviant within the pre-change scene it would be necessary to categorize the remaining five images. The behavioural results however suggest that this is not done. The replacement of pre- and post-change scene hence answers for the significantly higher detection rates for local as compared to global mismatch signals and the absence of a behavioural interaction in the present experiment. Therefore the interaction obtained in the third experiment is mediated by the categorization of the single stimuli in the pre-change scene. The position of the homogenous category might also explain the lack of an interaction in the ERP components that react either to the local or global exogenous cue in the third experiment. This argument will be broadened in the following sections.

ERP effects induced by global deviations (semantic)

No effect of the global deviation is found in the pre-change image. It was assumed that a semantic deviation effect should be seen if the semantic deviant results of the third experiment are due to a within scene comparison of deviant and categorical stimuli. This however could not be found. Thus it is likely to assume that the effects of semantic deviancy in the previous experiment are due to a comparison between pre- and post-change scene as is true for the perceptual deviants.

The results thus suggest that the pre-change image is not categorized even in the cases of within category changes. This might be due to two reasons. First, the post-change image is semantically fully categorized and therefore constitutes the category standard as opposed to the within category cases of the pre-change scene. Second, the mentioned semantic deviant (present in half of the images) might oppose categorization of the other half due to expectation effects. Participants might not perceive the within category cases of the pre-change scene as categorizable especially because the post-change image clearly is. Nevertheless the absence of a differentiated ERP effect due to the deviancy of the exogenous semantic cue is a sign in favour of the assumption that the cueing effect on change blindness is due to comparison between scenes rather than comparison of the deviant to the category items within the scene.

The analysis of global deviants in the post-change image revealed an enhancement of the P3 for changes within a category. As in the third experiment, in which a N170 is evoked by the increasing familiarity with the category, the P3 effect found in the present experiment reflects the importance of categorization over deviants in the experiments (for a similar argumentation see literature on Gestalt psychology: Helson, 1933; Wagemans, Elder, et al., 2012; Wagemans, Feldman, et al., 2012). The P3 is elicited by homogenously categorized scenes, which therefore seem to be better internally represented. The enhanced P3 in reaction to categorized scenes might be an expression of a mismatch of the good gestalt in an experiment where deviants dominate (Donchin, 1981). The fourth experiment again presents deviants in three thirds of the trials. Thus the subjective standard in the present experiment might be set to the processing of deviants. In the trials with changes within a category the semantic category is homogenous in the pre- as well as the post-change scene. Thus these trials are a mismatch to the standard formed in the experiment and increase the P3. Furthermore, an interaction effect of semantic and perceptual deviancy could be found in the P3 time interval. The P3 component was increased under minor perceptual deviances for within category changes. This effect further supports the argument that homogenous categories increase the P3 component. The expectation for a deviant to occur in a trial is the most violated if the perceptual deviancy is minor and the change is within a category and thus elicits the P3.

The modulation of the ERP components in the post-change scene by the deviance condition presented in the pre-change scene is in favour of the assumption that memory processes in the comparison between the scenes are responsible for change detection. The N170 found in the previous experiment and the P3 found here seem to reflect memory processes by the modulation of familiar or categorized stimuli. Hence, the inducement of a P3 as an expression of memory processes adds evidence to the conclusion that representations of the pre- and post-change scene are stored and compared. The lack of a replicated N170 effect of semantic deviation in the post-change scene might be due to the need for categorisation in this scene. For a more detailed discussion of this argument see the section below on ERP effect of perceptual deviants.

ERP effects induced by local mismatch signals (perceptual)

The ERP results for the post-change image show that the degree of a perceptual deviation interacts with the degree of semantic deviation and that there is a not significant trend for an effect on early visual processing. The not significant increase of the N1 amplitude induced by minor perceptual changes mirrors the significant one found in the previous experiment.

In contrast to the third experiment the perceptual deviancy does not significantly modulate early processing. The rearrangement of deviants in the pre- and post-change scene may account for the missing effect on early components, which was found in the previous experiment. The post-change image should be automatically categorized within the first 150 ms (Fabre-Thorpe et al., 2001; VanRullen & Thorpe, 2001). This might interfere with the early processing of the change stimuli in the P1 and N1 time interval as well as the N170 in reaction to semantic deviants.

The effect of perceptual processing on the P3 from the third experiment is seen in the present experiment only in interaction with the semantic processing. Additionally to the interaction described above in the section on semantic deviants, major perceptual deviants enhance the P3 amplitude if the change is also between categories. Thus the effect of perceptual deviancy on the P3 depends in the fourth experiment on the semantic deviancy. Otherwise the direction of the effect with an enhancement for major perceptual deviancy is the same as in the previous experiment. The P3 as a mismatch detector is elicited by the perceptual deviant if the deviancy is further enhanced by a between category change.

ERP effects induced by unspecific changes

Replicating the effect of an unspecific change on the ERP components N1 and P3 in the third experiment, both components are again enhanced ipsilateral to the change irrespective of the deviant condition. Thus it might again be that a) the change itself serves as a local mismatch to the stored representation of the pre-change scene or b) that the exogenous cue is able to capture attention to the change position although it is present in the pre-change scene in the fourth experiment. In contrast to the previous experiment the P1 and N2pc are also modulated by the cued change. Both components are increased contralateral to the change. This is in line with the literature on these components.

The P1 is evoked by attended stimuli on the contralateral hemisphere (Luck, Fan, & Hillyard, 1993; Luck et al., 1990; Luck & Hillyard, 1994, 1995; Mangun & Hillyard, 1991; Martinez et al., 2006). Attentional shifts in visual search tasks are also related to the N2pc component. This component is more pronounced contralateral to the spatial position of the attended item in a visual search display (Luck & Hillyard, 1994; Luck et al., 2000; Schankin & Wascher, 2007, 2008). Thus both components are also elicited by attention allocation to the change position, as are the ipsilateral N1 and P3. That even more components are evoked by the attention allocation is a result in favour of the assumption that the exogenous cue captures attention. If the cue is presented in the pre-change scene attention is already allocated to the change position of the post-change scene. If the cue is presented in the post-change scene it has to capture attention and thus it might be that fewer attention related ERP components are elicited. The change however is always present and no difference between the experiments is evident in relation to the changes but only in relation to the cue position. Thus it might be that the difference in components elicited by unspecific changes between experiments three and four is due to the change of cue position and it can be concluded that the exogenous cue captures attention reflected in these components.

Interaction of the processes

The results of the third experiment presented here suggest that categorization of single objects is able to create a context and has effects on the processing of following images. The transfer of a current model of context to the detection of a change is apparent in the behavioural and electrophysiological data concerning change detection in the previous experiment. The present experiment shows that perceptual and semantic deviants are again able to reduce change blindness although the role of semantic deviants is reduced due to the impossibility to previously form a categorical standard.

The results of the change detection task and the ERP data support the idea that perceptual as well as semantic attributes of visual objects are processed and influence change detection according to their deviancy to the pre- (third experiment) or post-change (fourth experiment) object in a given categorical context. It is however obvious that the processing of perceptual and semantic deviants differs. As in the third experiment, behavioural and electrophysiological data differ in their modulation by the cue types. In the previous experiment perceptual and semantic deviancy interacted on the behavioural (output) level but was independent on the electrophysiological (processing) level. In the present experiment this is reversed. The presentation of the deviant in the pre-change scene led to independence on the behavioural level and interaction on the electrophysiological level.

In the previous experiment, perceptual deviants are processed earlier than semantic deviants (at 80-110 ms and 120-150 ms for perceptual and at 150-180 ms for semantic deviants) and elicit a P300. This is reflected in higher detection rates. As argued above the interaction in the change detection rates might be due to mediation by context. In the present experiment the local (perceptual) and global (semantic) deviants are independent in the behavioural analyses. Perceptual deviants are detected significantly better than semantic deviants and as opposed to the third experiment both effects do not interact. This independence however is not reflected in the ERP data. Semantic categorization has an influence on the P3 component (300-500 ms). But perceptual and semantic deviancy also interacts in the modulation of the P3.

This interaction can be seen as support for the assumption that a homogenous categorical context mediates the role of semantic and perceptual stimuli features on visual search. In the third experiment the homogenous category of the six single objects in the pre-change scene forms a context or standard that defines which object is deviant in the post-change scene. This context standard might mediate the effect of both cue types and leads to interaction on the output level although they are independent on the processing level. This might be due to parallel processing on the routes for “vision at a glance” and “vision with scrutiny” (Hochstein & Ahissar, 2002) as well as a separate categorisation process. In the fourth experiment the context standard cannot be formed in the pre-change scene due to the presence of the deviant in this scene. It seems that the reinstating of the homogenous category in the post-change scene does not mediate the effect of perceptual and semantic deviancy on the behavioural level where they are independent. On the electrophysiological level on the other hand the category is processed in the post-change scene and interacts with the processing paths of perceptual and semantic features expressed in an interaction of both cue types in the P3 component. The processing of the homogenous category in the post-change scene seems to mediate the effect of perceptual and semantic deviancy on the processing level as it did in the previous experiment on the output level. Furthermore the direction of the effects in the P3 component reflects the effect found for semantic and perceptual deviants in the third experiment although they are here modulated by the deviancy on the other feature. In experiment three major perceptual deviants enhanced the P3. The same is true for the fourth experiment for major perceptual deviances for between category changes. Additionally in the previous experiment changes within a category increased the N170 reflecting familiarity with a category. Experiment four shows an enhanced P3 for within category changes as an expression of the subjective probability of homogenous categories for minor perceptual deviances. Thus both components show increased processing for sustained homogenous categories in an experiment where attention is captured to deviants.

The P3 component might be sensitive to local and global mismatches mediated by the context. The local mismatch of the perceptual deviant is further enhanced by the presence of a semantic deviant. On the other hand, the global deviant (homogenous context) increased the P3 for changes within a category when the change was also perceptually similar. Without the context as mediator only the perceptual deviance seems to be able to modulate the P3 component (see experiment three).

Surprisingly, the early components were not affected by either perceptual or semantic deviancy in the current experiment as opposed to the previous one. This could be due to the fact that in experiment three the context might have been analysed in the pre-change scene and the perceptual (P1 and N1 component) and semantic deviancy (N170 component) in the post-change scene. In experiment four the categorical homogenous context could not be analysed until the post-change scene. Thus it might be that the categorisation of the semantically homogenous stimuli interferes with the expression of deviancy processing in early components. Thence, in the post-change scene the analysis of deviancy takes place only in a modulation of the late component P3.

Thus the third and fourth experiment are in favour of the explanation that the conflicting results concerning the predominance of perceptual or semantic stimuli features are due to the categorical/semantic context. It seems likely that a clear categorical context mediates the role of perceptual and semantic stimuli features for visual search. The context thus has to be systematically controlled in experiments designed to compare the influence of both stimuli features.

Another explanation for the conflicting results concerning the advantage of either semantic or perceptual attributes in visual search found in the literature might be timing issues. In the present experiment - given the one-shot flicker paradigm - subjects were under considerably higher time pressure than in most change blindness experiments in which the original and modified scenes flicker as long as the participants need to detect the change and respond (or a relatively high time limit is arrived). It is easily conceivable that under lesser time pressure the advantage of the perceptual deviants due to the earlier processing might disappear. However, the context mediator assumption seems more parsimonious given the fact that this variable differs in the reviewed studies on the influence of perceptual or semantic features in visual search (Pringle et al., 2001; Stirk & Underwood, 2007).

At this point it is necessary to discuss if the joint analysis of detected and not-detected trials done in experiment three and four is possible. The early components analysed (P1, N1, N170) are not directly modulated by awareness (Lamy, Salti, & Bar-Haim, 2009) but can be seen as prerequisites of awareness (Aru & Bachmann, 2009; Koivisto et al., 2009).

The P1 and N1 as expressions of a gating process for attended stimuli (Eimer, 1993) are important for the internal representation of these stimuli and this representation can lead to awareness (Koivisto et al., 2009). Therefore it is not necessary to separately analyse the detected and not-detected trials for the early components. Change items in trials in which subjects did not state change detection could nevertheless have excited spatial attention and therefore elicited the P1 and N1. The N170 and the P2 as signs of categorization/memory processes are also not sufficient prerequisites for conscious detection (Federmeier & Kutas, 2002; Scott et al., 2008).

The P300 in contrast is assumed to be sensitive to change detection (Koivisto & Revonsuo, 2003; Niedeggen et al., 2001). Detection, however, is not the only modulation of the P300. This component is also modulated by probabilities, expectancies, and the deviancy of stimuli to the context (Donchin, 1981; Verleger, 1988). Given the manipulations of the context and the deviancies of change stimuli in the third experiment a greater P300 to detected as compared to not-detected changes could be due to two reasons: 1) the awareness of the change or 2) the higher deviancy of the change stimuli. The same is true for the presented analysis. It is not possible to differentiate if the higher amplitude of the P300 to major perceptual changes in experiment three is due to awareness in the detected trials (included in the averages) or to the higher deviancy. In the fourth experiment the stated effect is repeated for major perceptual deviants of between category changes (major semantic deviance). Thus the effect could again be due to awareness or deviancy. Furthermore, the P3 seems to be an expression of awareness of the complete category in the within category condition for perceptually similar changes rather than change detection. The fact that the modulation of the P300 in these experiments can only be interpreted as a compound of awareness and deviancy renders it unnecessary to analyse detected and not-detected trials separately.

The effect of semantic and perceptual exogenous cues on the stability of representations

The recognition rates and reaction times found in the fourth experiment show a pronounced processing advantage for the pre-change items. This result is at a first glance in line with the first impression hypothesis that states that the pre-change scene is stored and change blindness arises because the post-change scene is not stored or updated in visual memory (Simons, 2000).

The comparison between experiment three and four showed a significant interaction of the between subjects factor experiment and word origin. This is in line with the assumption that the found processing advantage for post-change items of the third experiment are due to the salience of deviants e.g. the presence of the cue (Schmidt et al., 2002; Todd & Marois, 2004) rather than the first impression (present experiment) or overwriting hypothesis (third experiment). The presence of a cue is assumed to facilitate the storage of representations and result in higher recognition rates and faster reaction times. Following this hypothesis, the pre-change representation of the reversed experiment should show this benefit in the recognition rates and reaction times. This, indeed, is the case. Thus the presence of a cue in a given scene facilitates the stability of its representation.

As in the previous experiment for pre-change items, there is nevertheless proof for storage of the post-change item with significantly higher recognition rates than new items. This result is in contrast to the first impression hypothesis. The post-change scene is clearly represented although the trace is not as strong as that of the pre-change scene. This result also rules out the overwriting/retrieval blockage explanation that assumes the maintenance of the pre-change scene representation is hindered by the following storage of the post-change scene representation (overwriting hypothesis; Simons, 2000; retrieval blockage; Yeh &

Yang, 2009). Although the post-change scene is presented after the pre-change scene and should interfere with its representation, the pre-change item is better recognized. Yang and Yeh (2009) in the same vein argued that cueing could dissolve the retrieval blockage of the pre-change scene. It is therefore more likely that the exogenous cue facilitates the representation/maintenance of the pre-change scene representation through its deviancy.

Change detection influences the recognition rates and reaction times to recognized words. Change detection increases recognition rates for the pre- and the post-change item. Interestingly the increase is relatively small. As argued for the third experiment one might expect recognition rates near 100% for detected changes at least for the post-change item. This however is not found. Recognition for post-change items is increased from 39% to the level of about 50% and that of the pre-change item from 68% to 81%. Thus it is clear that the position of the cue rather than awareness of the change is responsible for the retrieval of an item from memory although detected changes also increase recognition.

In contrast to the increase of recognition rates due to change detection the reaction times are slowed down for detected changes. Although the analyses show no interaction of change detection and origin of word but only a main effect of change detection visual inspection does show that primarily the reaction time to post-change items is slowed down by change detection. As was argued in the previous experiment for the pre-change item this slow down might be an expression of retrieval blockage. If this is true than the cue is not only able to solve the blockage but can move it to the post-change item. It is however surprisingly clear that processes of change detection or short-term memory effects (Broadbent & Broadbent, 1981; Luck & Hollingworth, 2008) are not responsible for the recognition advantage of the pre-change item but the position of the exogenous cue that might facilitate the storage of representations through attentional capture (Schmidt et al., 2002; Todd & Marois, 2004).

ERP effects induced by word recognition

The differentiated processing of the pre-change items seen in recognition rates and reaction times is reflected in the electrophysiological data. Pre-change items reduced the N4 component. As stated above, the N4 - as a component reflecting memory search (Dunn et al., 1998; Picton, 1988) - is reduced by repetition priming (Stelmack & Miles, 1990). The N4 is reduced by the words relating to the pre-change scene. This result again argues for the assumption that the deviants placed in the pre-change scene are the paramount reason facilitating the storage of the scene. This is expressed in the presence of said priming effect for the pre- but not the post-change items or new items. Thus the significantly higher recognition rates of the post-change scene compared with the new item hinting at a representation of post-change items are not mirrored in the ERP data. The same was true for the third experiment where the significantly higher recognition rates of pre-change items compared with new items was not seen in the ERP data. Thus it seems that the recognition rates show a memory trace of both pre- and post-change item with much more stable representations for the scene holding the cue. It might be that normally representations of both scenes are formed possibly with an advantage for the post-change scene due to retrieval blockage or short-term memory processes. Cueing than facilitates the memory representation of the cued scene. Processes like the recency effect or other short-term memory processes as well as cueing might stabilize the representations enough to enable ERP signatures whereas the representation of the not-facilitated scene might not be stable enough to elicit the N4. Nevertheless this less stable representation increases recognition rates on the behavioural level. It is however clear that cueing facilitates the stability of representations and this effect is able to overcome retrieval blockage and short-term memory processes.

Conclusion

Exogenous local and global cues influence visual search and interact when mediated by context. Depending on the position of a homogenous context this interaction is expressed either on the behavioural/output level (experiment three) or the electrophysiological/processing level (experiment four). If a categorized scene context can be formed previously to the required change detection decision perceptual attributes are processed earlier than semantic attributes and gain an advantage in detection rates when fast responses are required and the semantic stimuli features enhance the role of the perceptual stimuli features. Perceptual deviancy triggers an early-stage sensory gating/discrimination process of attended stimuli that detects the perceptual change whereas semantic deviances need somewhat later categorization processes to be detected. If this context cannot be previously formed but is presented simultaneously with the required change detection decision the perceptual and semantic attributes are independent in their effect on the visual search performance although the processing of the attributes interacts due to the simultaneous processing of the categorical scene context. Again the perceptual attributes show an advantage on the output level with higher effect sizes than the semantic attributes. Nevertheless no differentiated time line can be seen for the processing of perceptual and semantic attributes in the ERP data but an interaction on the late component P3.

It can be concluded that both object attributes are processed relatively independent and only interact when the context promotes it either on the processing or output level. Furthermore in the presented experiments the perceptual deviants predominate in their influence on visual search.

The deviancy of the exogenous cue serves as a facilitator for memory processes as could be seen in the word recognition task. Recognition was enhanced by repetition priming of the scene containing the deviants. The results of the third and fourth experiment dispute the overwriting and first impression hypothesis (Simons, 2000) and argue for the significance of exogenous cues for the storage of information.

Furthermore the exogenous cue clearly captures attention to the change position as is expressed in an unspecific change effect in the electrophysiological data showing attention modulation by the change.

Experiment five

Semantic contextual cueing

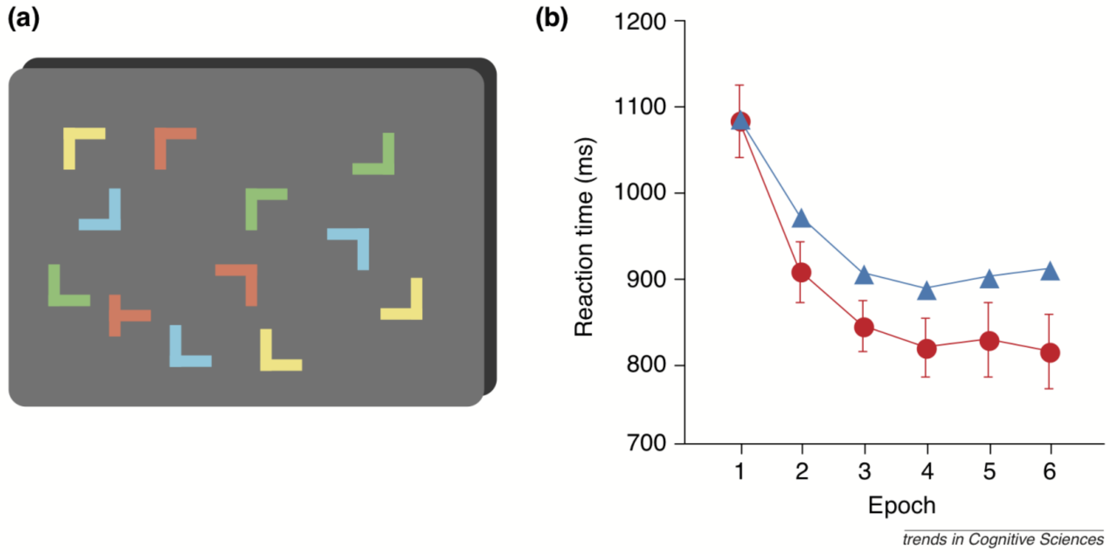
The fifth experiment was constructed to determine if a semantic context itself could exogenously capture attention to the location of the change through learning. As is clear from the previous experiments, the context mediates the impact of exogenous cues on visual search. The literature also highlights the role of categorisation and context for visual search (Antal et al., 2001; Antal et al., 2000; Bilalic et al., 2009; Fabre-Thorpe et al., 2001; Hollingworth & Henderson, 2000; Kelley et al., 2003; Rensink et al., 1997; Stirk & Underwood, 2007; Takahashi & Watanabe, 2008; Werner & Thies, 2000). Thus it is clear that the context is important in visual search. Through experiment three and four it could be seen that the categorical context can be used to highlight the role of semantic and perceptual deviants for visual search. But can the semantic context be used to guide visual search by itself? Can the category of the context become the exogenous cue that captures attention as did the deviants in experiment three and four or the lexical semantic cue in experiments one and two? To approach these questions the literature on contextual cueing of perceptual and semantic context will be reviewed and research questions will be evolved.

Memory traces of contextual regularities

One line of theories on the change blindness phenomenon states that change blindness takes place because in our everyday life we do not need to store visual information due to the availability of the visual world itself as the store for information (Ballard et al., 1995; O'Regan, 1992; Simons & Levin, 1997). This outside memory assumption would argue against the instance theory with its memory traces of visual displays (Logan, 1988). In our visual world we seldom encounter invariant visual displays that might render it unnecessary or inefficient to store traces of visual arrays. Nevertheless we do encounter typical, related configurations of objects in our everyday life. Although exact arrangements of objects might change many objects co-appear in certain contexts. The typical presence/configuration of objects or events in certain contexts is stored in memory as schemata or scripts (Abbott et al., 1985; Alba & Hasher, 1983; Bartlett, 1932; Schank & Abelson, 1977; Thorndyke, 1977). Schemata are higher-order cognitive structures of organized knowledge from a certain context (Bartlett, 1932). Scripts have an additional temporal component. They represent organized knowledge for sequences in certain contexts. Schemata and scripts provide knowledge about the typical contextual relationship between objects or actions and thus interact with new information (see also literature on expertise and the Einstellungs (set) effect, Bilalic et al., 2008, 2009, 2010; Takahashi & Watanabe, 2008; Werner & Thies, 2000). These cognitive structures can reduce the information that has to be extracted from a context due to previous knowledge already embedded in the context (Brewer & Nakamura, 1984). Therefore it might be that the human visual systems searches for contextual regularities in the visual world, which are then stored as traces rather than complex, detailed visual representations. The assumption that we store contextual regularities is supported by literature on expertise, implicit learning and memory, visual search, and object perception (Biederman, Mezzanotte, & Rabinowitz, 1982; Bilalic et al., 2009, 2010; Reber, 1989; Stadler & Frensch, 1994). In the implicit learning paradigm the presentation of stimuli follows a sequence. If this regularity is learned faster and more accurate reactions are possible due to the predictability of the next stimulus. Participants incidentally learn this stimulus sequence and show a performance advantage as compared to the presentation of random stimuli. Thus the contextual regularity e.g. the sequential order was stored and is used to adapt behaviour. This represents the fundamental adaptive function of learning as defined by Goschke and Bolte (2007). One phenomenon that uses contextual regularities to modulate visual search through learning is spatial contextual cueing. This phenomenon will be introduced in the next section.

The effect of spatial contextual cueing on visual search.

Contextual regularities can also be used as exogenous cues for visual search as is evident from search on the contextual cueing paradigm. Chun and Jiang (1998) introduced the contextual cueing paradigm. Contextual cueing refers to the benefit of repeated spatial configurations cueing the target position over configurations new to the subject. Therefore contextual cueing shows the possibility of implicit learning in visual search. The invariant context serves as a marker where to allocate attention to detect the target. Participants in their experiments incidentally associate the global configuration of distracters in the visual array with the position of the target when repeatedly exposed to the same context configuration. As presented in figure 36 old configurations (presented repeatedly) showed a marked advantage in the detection and discrimination of the target stimuli over new configurations (presented once).



trends in Cognitive Sciences

Figure 36. Figure reprinted from “Contextual cueing of visual attention” by Chun (2000), *Trends in Cognitive Sciences, 4*, p. 173, copyright (2000), with permission from Elsevier and Marvin M. Chun. (a) Stimulus display showing a typical configuration of distracters (L shapes) and target (T shape). (b) Reaction times to repeatedly presented (old) configurations as red dots and to once presented (new) configurations as blue triangles.

The authors propose that the implicit learning possibility created by the contextual spatial configuration leads to “highly robust, instance-based implicit memory for context.” (Chun & Jiang, 1998, p. 30). According to Chun and Jiang a context map is build that determines how bottom-up perceptual information and top-down (memory) modulations should be activated to allocate attention. Traces of meaningful (e.g. predictive) components of the visual display are then stored and reactivated and strengthened with repeated exposure to the same or similar components according to Logan’s instance theory (1988). These instances then lead to automatization of the search process with enhanced performance (Logan, 1988). Chun and Jiang (1998) state that these implicit context maps and instance based search is more beneficial to search performance than a general search algorithm which also improves over time.

The authors tested if the memory for the context is indeed implicit with a recognition test. The participants were asked if they noticed the repetition of certain configurations. Independent of the answer all participants had to conclude the recognition test where they had to indicate if they recognized a presented configuration. They were presented with 12 repeated configurations from the experiment and 12 newly generated configurations. Only a small magnitude of participants stated to be aware of repeated configurations and their amount of the contextual cueing effect did not differ from unaware participants. Furthermore they were only slightly better at recognizing old configurations than unaware participants.

These were not able to discern old from new configurations. Hence, Chun and Jiang concluded that the contextual cueing effect relies on implicit memory that is incidentally acquired (Chun & Jiang, 1998, p. 45).

The spatial configuration of a scene thus is implicitly stored as instances and is used to adapt behaviour. Could this effect be transferred to a semantic context? Literature that suggests this possibility is compiled in the next section and is used to develop research questions and the subsequent hypothesis.

The effect of semantic contextual cueing on visual search

According to the literature on schema theory, the use of semantic or contextual regularities should reduce effort needed in information processing. This might also be true for visual search tasks such as change blindness. Therefore the question is:

Q 1: Can the spatial contextual cueing effect (Chun & Jiang, 1998) be transferred to a semantic contextual cueing paradigm?

The Hollingworth and Henderson experiments (2000) clearly show that the context of a relatively simple scene is processed and used to detect schematic deviations. Brockmole and Henderson (2006b) used photographs of real-world scenes in which the target letter was embedded. They were able to show that repeated photographs elicited a clear contextual cueing effect. The inversion of the photographs reduced the contextual cueing effect showing that semantic contextual information rather than spatial configuration evoked the contextual cueing effect. In another experiment Brockmole, Castelhano, and Henderson (2006) showed that the global rather than the local real world context of the target position is responsible for the contextual cueing effect. This further supports the assumption that the contextual cueing effect can also be evoked by a semantic rather than a spatial context. If only the local configuration of contextual objects had been sufficient for the contextual cueing effect to take place one could have argued that spatial configuration rather than semantic contextual information is responsible for the effect (figure 37).

It thus seems clear that a semantic real-world context can elicit the contextual cueing effect and it can be hypothesized, that:

H 1: A semantic context is able to predict the change position and reduce change blindness rates and reaction times.

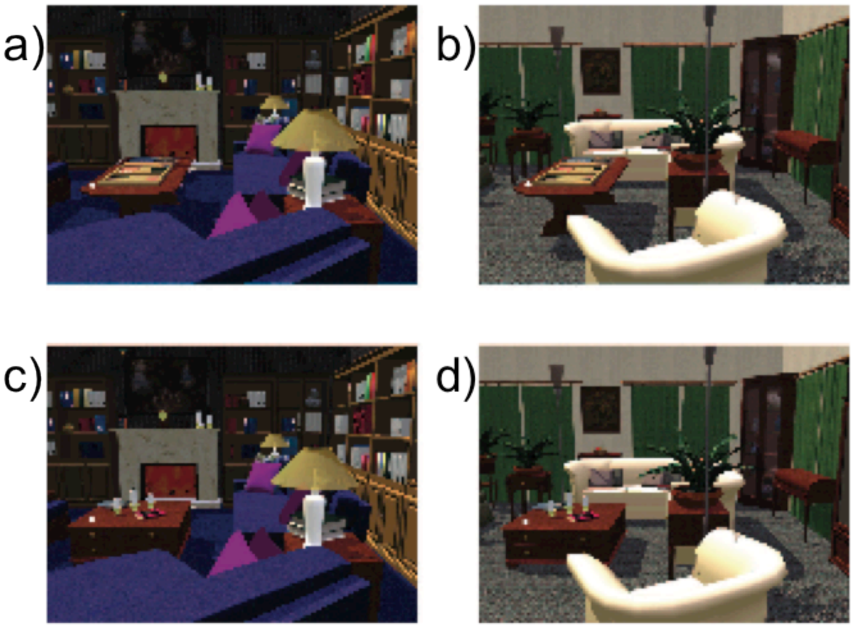


Figure 37. Conditions of the local and global context variation in the experiments from “Contextual Cueing in Naturalistic Scenes: Global and Local Contexts” by Brockmole, Castelhano, and Henderson (2006), *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, p. 700. Copyright 2006 by APA. Reprinted with permission from James Brockmole. The local context is varied between scene a) and c), as well as b) and d) with the change of the table and the objects on the table. The global context is varied between scene a) and b), as well as c) and d).

According to Chun and Jiang (1998) the contextual cueing effect relies on implicitly learned regularities of the spatial outlay of the scene. Implicit learning is the nonintentional and automatic acquisition of knowledge about structural relations between objects or events (Frensch, 1998). As stated above categorisation of semantic stimuli is a rapid automatic process. It thus seems likely that a semantic context that is predictable of a target position is implicitly learned. Nevertheless Brockmole and Henderson (Brockmole & Henderson, 2006a, 2006b) showed that their participants were aware of repeated photographs. This can be explained by the difference between stimuli displays. In the spatial contextual cueing paradigm several single objects form a spatial configuration whereas in the Brockmole and Henderson experiments photographs of real-world scenes were repeated. The semantic context of the real world scenes leads to information reduction through chunking and the interaction with schemata of such contexts (for example a living room with the typical objects found in this context). Thus the context reduces resources needed for scene processing and acts as an additional cue to retrieve the scene from visual memory stores thus making it much easier to recognize throughout the experiment as well as in an adjacent recognition test. Hence the question is:

Q 2: What is learned in a semantic contextual cueing paradigm?

In the contextual cueing paradigm the relationship between global spatial layout of repeated displays and the location of the target is learned implicitly (Chun & Jiang, 1998, 1999). In the semantic contextual cueing experiments by Brockmole and colleagues the relationship between global semantic context of repeated real world scenes and target location is explicitly learned (Brockmole et al., 2006; Brockmole & Henderson, 2006a, 2006b). As stated above the difference between explicit and implicit learning in the spatial and semantic contextual cueing seems to be due to the possibility for information reduction in the semantic contextual cueing experiments. If this possibility for information reduction is not given, learning might again be implicit. Thus in the present experiments scenes are used that are more similar to the displays in the classical contextual cueing experiments.

Participants are presented with single objects from a common category. The category of the single stimuli predicts the change position. The specific stimulus displays are not repeated but rather the category that they form and that predicts the change position. Thus they share a common category but cannot be chunked or activate schemata as do the real world scenes in the Brockmole and colleagues experiments. Nevertheless, the context of the scene (the semantic category of the single objects) predicts the change position, as does the spatial configuration in the original paradigm and the semantic contexts in the Brockmole and colleagues experiments. Therefore this design might lead to implicit rather than explicit learning of the relationship between global semantic context and change position.

Another reason for the difference between the spatial and semantic contextual cueing experiments reviewed above could be that semantic categories are explicitly processed. In contrast to this assumption Goschke and Bolte (2007) were able to show that participants learned implicitly in a serial reaction study using a sequence of categories. They used stimuli from four different categories. The stimuli or responses themselves did not follow a sequence but the categories of the specific stimuli did. This regularity in the categorical sequence was incidentally learned and speeded reaction times up. Only one third of the participants were able to verbalize at least parts of the sequence whereas the remaining participants learned the categorical sequence implicitly. This study shows that the effect of semantic categories does not have to be explicit to influence the acquisition of knowledge about structural relationships. It therefore can be hypothesized that:

H 2: The relationship between the semantic category of the scene display and the change position is implicitly learned and reduces change detection and reaction times.

As in the former experiments ERP data was recorded in addition to the behavioural data. The event related potentials could shed light on the question if implicit learning of the contextual regularities is possible in the present semantic contextual cueing task. ERP components are able to shed light on implicit processes in addition to purely behavioural measures (Li et al., 2002; Matt et al., 1992). Thus the question is:

Q 3: Is the effectiveness of the semantic contextual cueing paradigm reflected in the ERP data?

One component repeatedly associated with serial learning is the P3 component. The P300 complex is assumed to reflect awareness and detection, which should be higher for semantic contexts predicting change positions (Koivisto et al., 2009; Koivisto & Revonsuo, 2003). On the other hand, the P300 is a component reflecting mismatch detection (Donchin, 1981; Duncan-Johnson & Donchin, 1982). Hence, it should be elicited in the random blocks where the expectation that a certain category predicts a certain spatial region is destroyed. Therefore the random blocks present a mismatch to the expected relationship between categories and region containing the change position. Studies researching the electrophysiological components in serial learning paradigms found that stimuli destroying the sequence elicit a higher P3 (Baldwin & Kutas, 1997; Eimer, Goschke, Schlaghecken, & Stürmer, 1996; Rüsseler, Hennighausen, Münte, & Rösler, 2003; Rüsseler & Rösler, 2000). Nevertheless it is debatable if this is only true for explicit learning of the regularity (Rüsseler et al., 2003; Rüsseler & Rösler, 2000). Eimer et al. (1996) and Baldwin and Kutas (1997) however showed an enhanced P3 independent from explicit or implicit learning for deviant stimuli. Thus it seems that in serial learning the mismatch detection aspect of the P3 complex is active and it can be hypothesized that:

H 3: The P3 is enhanced in blocks without a predictable relationship between category and change position of the post-change scene.

Although the focus of ERP analyses lies on the P3, the components found in the previous experiments associated with attention are also taken into consideration. Processes reflecting learning in the pre-change scene might already elicit the ERP components modulated by attention. If the predictability of the different categories is encoded an attentional shift to the predicted change positions might be made after the categorization of the present stimuli is completed. This effect should also be seen in the post-change scene were attention has also be allocated to the change positions. If participants are able to learn the predictability of the semantic context their attention should be drawn to the predicted change positions which should be detectable in a variation of the early ERP components P1 and N1 which are assumed to be modulated by focused attention in visual search (Luck et al., 1990). The same is true for the N2pc component that reflects attentional shifts to a target (Schankin & Wascher, 2007, 2008). It thus can be hypothesized:

H 3a: ERP components related to attention allocation show attentional shifts to the predicted change positions over the predictable blocks but not in the random blocks of the pre-change scene.

H 3b: ERP components related to attention allocation show attentional shifts to the predicted change positions over the predictable blocks but not in the random blocks of the post-change scene.

The effect of semantic contextual cueing on the stability of visual representation

After the change detection task a repetition priming task was again presented to test if learning enhances the stability of visual representation. According to the previous experiments the representation of scenes depends on the design of the experiment rather than general storage principles (overwriting/first impression hypothesis or recency/retrieval blockage). The question therefore is:

Q 4: Does the semantic contextual cueing design facilitate the stability of visual representations?

The exogenous cue (predictive context) captures attention to a specific location. According to the logic of cueing the captured attention stays on the cued locations and thus enables the formation of stable visual representation of the pre-change as well as the post-change item (Schmidt et al., 2002). Nevertheless as is clear from experiment three and four the position of the cue or the deviant influences the stability of visual memory representations. In the present experiment however the context is the cue and thus present in the pre- and post-change scene. The context predicts the change positions in the learning blocks. If this relationship is learned attention should be drawn to the change positions and the stability of the representations heightened (Schmidt et al., 2002). Thus it is reasonable to assume that the stability of representation should increase with learning. In blocks without this predictive relationship no cue to capture attention is present. Thus in the random blocks attentional processes due to cueing cannot enhance the stability of memory representations. If the experimental design adopted in the fifth experiment enhances the formation of stable representations in the blocks with a predictive relationship between category and change positions this should lead to enhanced confidence for the recognition decision and thus faster reactions (Eimer & Mazza, 2005; Kutas & Van Petten, 1994; Mitroff et al., 2002). Therefore it is hypothesized that:

H 4: Semantic contextual cueing facilitates representations in the predictive blocks (learning and test blocks) as compared to the random blocks expressed in higher recognition rates and lower reaction times.

ERP data is again recorded to estimate the stability of visual representations. From the previous experiments it is clear that the repetition priming effect of the behavioural data is reflected in a N4 repetition effect. Hence, the question is:

Q 5: Is the hypothesized enhancement of stable representations in the behavioural markers due to learning reflected in the N4 priming effect?

Stable representations should elicit a N4 priming effect in the repetition priming task (Schnyer et al., 1997). As argued for recognition rates and reaction times the predictive relationship between category and spatial region containing the change should facilitate the stability of pre- and post-change representation due to the capture of attention to said region. This effect of stabilizing the pre- and post-change item representation due to semantic contextual cueing should be absent in the random blocks. And it thus can be hypothesized that:

H 5: Semantic contextual cueing facilitates the formation of stable representations expressed by an increased N4 priming effect for the learning and test blocks as compared to the blocks without a predictive relationship of category and change position region (random blocks).

Method and Material

Participants

EEG and behavioural data from 24 subjects were recorded. Due to artefact correction or a trial number too low to analyse, respectively, seven participants had to be removed from the analyses. Analysed data contained 15 right-handed and 2 left-handed (9 female, 8 male; aged between 18 and 52; mean age: 29.7) with German mother tongue, and normal or corrected-to-normal vision.

Stimuli

The setting and stimuli were the same as in the third and fourth experiment. Stimuli for the fifth experiment were taken from the pool of stimuli of the third and fourth experiment. The chosen stimuli were the ones from the categories animals, furniture, and household appliances. The categories were randomly chosen based on the result of the previous experiments that the detection rates and times do not differ between the categories. 144 trials were created. Every trial was constructed by randomly choosing six line drawings from the pool of items belonging to one of the three semantic categories. Thus trials belonging to the same category consisted of different single line drawings. Trials in which the same six line drawings were chosen by the random procedure were discarded. Thus, no two trials from one category consisted of the exact same six line drawings. This was done to ensure that the category and not the specific single items was learned. The original line drawing (pre-change item) was always replaced by an image of the same semantic category (post-change item). Care was taken to ensure that pre- and post-change item were perceptually similar as was defined in the experiments three and four.

Again target words were presented naming in ⅓ of the trials of the to-be changed line drawing of the pre-change scene or the changed drawing of the post-change scene or an unrelated line drawing (i.e. one not represented in the current trial but familiar from other scenes) followed by the array of digits (1-6) referring to the positions of the six line drawings.

Experimental variables and procedure

The procedure of a single trial was the same as in the third and fourth experiment *(see figure 38)*. To see if learning reduces change blindness the structure of a classical implicit serial learning experiment is adopted for the fifth experiment. The trials are partitioned into eight blocks with 18 trials each.

The first 4 blocks are learning blocks in which the category of the presented line drawings reliably cued the change positions. A category cued two possible change positions one of which was always changed. Thus the category cue is 100 % valid. The cued change positions were neighbours: one category cued positions 1 and 2, one category cued positions 3 and 4, and one category cued positions 5 and 6 as depicted in figure 39. Blocks 5 and 6 are random blocks in which the same categories are presented but the position of the change item is random. This renders the categorical exogenous cue invalid in these blocks. The last two blocks are test blocks in which the categories again cue the change position validly.

Therefore the location of the changed item was 100 % validly cued in the learning and test blocks by the category of the scene. The assignment of the categories animals, furniture, and household appliances to the change locations (1/2, 3/4, 5/6) was balanced over participants. Thus it was varied over participants which change locations were predicted by a specific category.

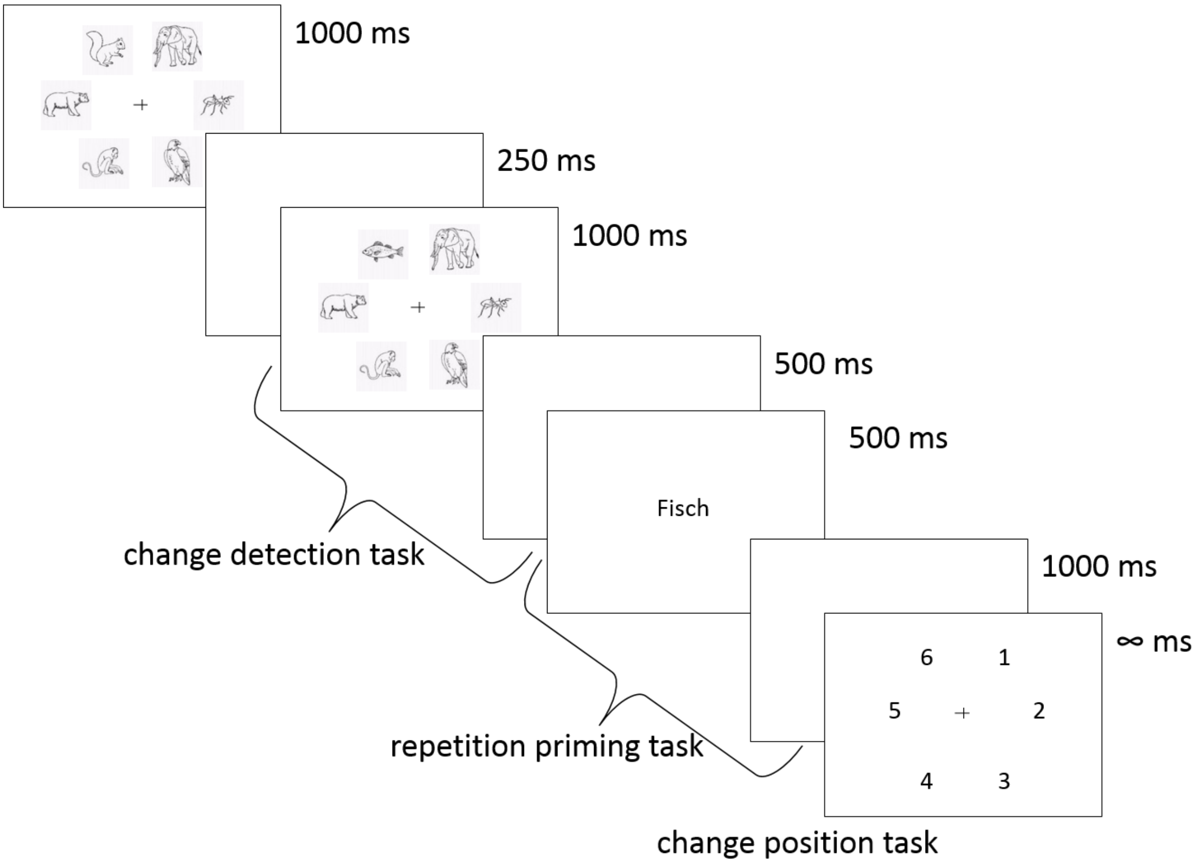


Figure 38. Two images with six circular presented line drawn objects were presented for each 1,000 ms, interrupted by a blank screen for 250 ms. The ‘flicker’ prevented the detection of a local object exchange. Participants had to indicate if they recognized the change with a key press on the E-Prime SRBox. Afterwards the target word was presented for 500 ms and participants had to indicate if the target word was present in the change detection scenes with a key press. At the end of the trial, subjects were to specify on which position (1-6) the change took place via key press.

The execution of the experiments took approximately 40 minutes and therefore the whole space of time from the information about the procedure unto the debriefing was about 90-110 minutes.

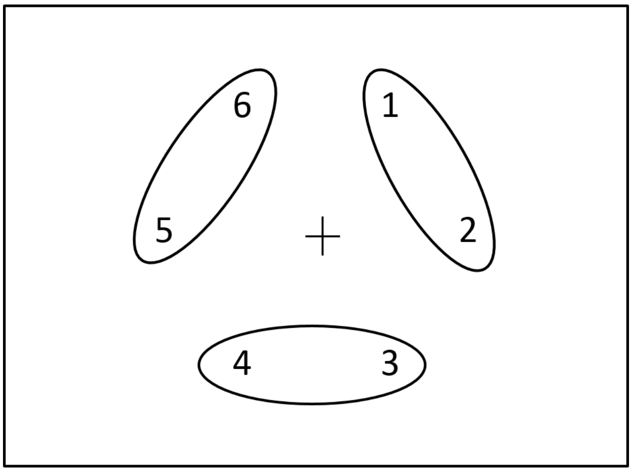


Figure 39. Line drawing positions in the fifth experiment. Circled are the pairs of possible change positions predicted by the three different categories.

EEG data recording and analysis

EEG was recorded (Psylab recording software, BioAmplifiers, Contact Precision Instruments, London) at 6 Ag/AgCl electrodes equidistantly positioned on the scalp in pairs of central (C3, C4), parietal (P3, P4) and parieto-occipital (PO9, PO10) electrodes and referenced to linked mastoids and electrode position Fcz as ground, and vertical and horizontal EOGs (vEOG, hEOG). The reduced number of electrodes used in the present experiment is due to the focussing of the ERP analyses on the P3 concerning the serial learning aspect of the experiment. This component is found at parietal electrodes. Nevertheless all other components analysed here are also found at central or parietal electrodes. To account for lateralised potentials pairs of electrodes are chosen which are able to indicate this lateralisation. Thus the number of electrodes is reduced with the additional benefit of a shorter preparation time for the participants.

For each participant and each electrode, artefact-free trials were averaged according to the pre- and post-change image and the target word. The pre- and post-change images as well as the target words were averaged according to the block and the change positions (1/2, 3/4, 5/6). Grand-averaged ERP potentials were used to define the temporal segments reflecting separate ERP components (for the pre- and post-change image - P1: 80-110 ms, N1: 120-150 ms, N2pc: 150-180 ms, P3: 350-500 ms, for the target word – N4: 300-500 ms).

Experimental design

In order to examine the effect of semantic contextual cueing on visual search.

On the behavioural level, mean change detection rate and reaction times are dependent variables and are computed for each participant separately for the pairwise averaged blocks: 3 and 4, 5 and 6, and 7 and 8 are averaged. Blocks one and two are not included in the analysis due to the fact that the relationship between category and change positions has to be learned in these blocks but it can be supposed that the learning is not stable in the first blocks. The remaining blocks are averaged pairwise to effectively compare learning (3/4), random (5/6) and test blocks (7/8). It is possible that the three categories show different learning curves due to their cued change positions (category one cued positions 1/2, category two cued positions 3/4, category three cued positions 5/6). Successful change detection requires that (a) subjects indicated to detect a change by pressing the button, and (b) that the subsequent localization of the change is correct.

Independent variables in the two-factorial repeated measurement design are change positions (1/2, 3/4, 5/6) and aggregated block (3/4, 5/6, 7/8).

Dependent variables in the electrophysiological analyses for the effect of predictability are ERP potentials in reaction to the onset of the pre- and post-change scene. Mean amplitudes for the four consecutive time ranges (P1, N1, N2pc, P3) are computed separately for the independent variables. Independent variables in the three-factorial repeated measurement design are change positions (1/2, 3/4, 5/6), aggregated block (3/4, 5/6, 7/8), and electrode. The independent variable hemisphere (ipsilateral vs. contralateral to the change) is included for the categories with the change positions 1 and 2 (right side of the presented image) and the change positions 5 and 6 (left side of the presented image) resulting in a four-factorial repeated measurement design. The category with change positions 3 and 4 cannot be included because the change positions are on the right and left side of the presented image. Analyses considering the factor hemisphere are always done additionally to the analyses including all categories to reveal a possible lateralized effect in the ERP components.

In order to examine if the semantic contextual cueing design facilitates the stability of visual representations.

Dependent variables for the behavioural analyses of the repetition-priming task are recognition rates and reaction times. Independent variable for both one-factorial repeated measurement designs is block (learning blocks 3/4, random blocks 5/6, and test blocks 7/8). For the electrophysiological analyses dependent variables are again ERP potentials in reaction to the target word. Mean amplitudes for the N4 time range are computed separately for the independent variables. Independent variables in the two-factorial repeated measurement design are aggregated block (3/4, 5/6, 7/8), and electrode. It is important to note that only the pre- and post-change item but not the new item is included in the analyses. This is due to the fact that here the influence of learning on the stability is important and learning should not influence the representation of an item not presented in the trial.

Results

The effect of semantic contextual cueing on visual search

Behavioural data (Figure 40):

In the fifth experiment, participants detected the change between the images in about 42-88% of the trials depending on the block and the category. The upper row of figure 40 shows differentiated reactions to the change positions predicted by the categories. Two categories change positions in learn and test blocks at position 1 and 2 and positions 5 and 6, respectively. The reactions to these change positions are quite similar in their response pattern, whereas the change positions 3 and 4 shows different results. For change positions 1 and 2, and change positions 5 and 6 an increase in detection rates from learning block 1 to 4 as well as the test blocks 7 and 8 can be seen and a pronounced drop of detection rates in the random blocks. Change positions 3 and 4 show a slight increase from learning to test blocks - although on a reduced level – and in contrast to change positions 1/2 and 5/6 a significant increase for the detection rates in the random blocks.

The repeated measures ANOVA with the factors block (3/4, 5/6, 7/8) and change positions (1/2, 3/4, 5/6) showed an interaction effect block*change positions (F (4, 64) = 8.33, $p < 0.001$, $\eta_p^2 = 0.342$) but no main effects (block: F (2, 32) = 1.49, $p = 0.243$, $\eta_p^2 = 0.085$, change positions: F (2, 32) = 3.18, $p = 0.055$, $\eta_p^2 = 0.166$). As described above, the detection rates of change positions 1/2 and 5/6 drop in the random blocks as opposed to change positions 3 and 4. This is reflected in the post-hoc ANOVA for blocks (3/4, 5/6, 7/8) and change positions (1/2 and 5/6) that revealed a main effect for block (F (2, 32) = 5.57, $p = 0.009$, $\eta_p^2 = 0.258$) and change positions (F (1, 16) = 4.67, $p = 0.046$, $\eta_p^2 = 0.226$) but no interaction ($F < 1$). The significant effect of change positions is due to higher overall detection rates for change positions 1/2 (M = 74.88) than 5/6 (M = 65.82). Nevertheless, the lack of an interaction effect shows that the categories differ in the degree of detection rates but not in the learning curve, which is the relevant factor. Thus they will be jointly analysed in the following sections. Follow-up t-tests for the detection rates of change positions 1/2 and 5/6 showed a significant reduction of change detection rates between learning blocks 3/4 and random blocks 5/6 (t (16) = 2.27, $p = 0.037$) and a significant increase in detection between random blocks 5/6 and test blocks 7/8 (t (16) = -3.28, $p = 0.005$).

A further ANOVA with the factors block (3/4, 5/6, 7/8) and change positions (1/2 and 5/6 vs. 3/4) showed a main effect of block (F (2, 32) = 3.96, $p = 0.038$, $\eta_p^2 = 0.199$) and a significant interaction of block and change positions (F (2, 32) = 14.59, $p < 0.001$, $\eta_p^2 = 0.477$) but no effect of change positions (F (1, 16) = 1.8, $p = 0.198$, $\eta_p^2 = 0.101$). The interaction is due to the difference in the learning curves. As stated above change positions 1/2 and 5/6 show a drop in detection rates in the random blocks whereas change positions 3/4 show an increase in the detection rates of these blocks. Due to these differences change positions 3/4 are separately analysed. The repeated measures ANOVA for change positions 3/4 with factor block (3/4, 5/6, and 7/8) also revealed a main effect of block (F (2, 32) = 11.65, $p < 0.001$, $\eta_p^2 = 0.421$) although in the opposite direction. Follow-up t-tests showed a significant increase of change detection rates between learning blocks 3/4 and random blocks 5/6 (t (16) = -3.96, $p = 0.001$) and a significant decrease in detection between random blocks 5/6 and test blocks 7/8 (t (16) = 3.41, $p = 0.004$).

The reaction times to the discovered changes do not differ between the change positions. The repeated measures ANOVA with the factors block and change positions showed only a significant main effect of block (F (2, 32) = 6.31, $p = 0.006$, $\eta_p^2 = 0.283$) with a linear decrease in reaction times over the blocks but no significant effect for change positions (F (2, 32) = 1.91, $p = 0.174$, $\eta_p^2 = 0.107$) or the interaction block*change positions (F (4, 64) = 1.23, $p = 0.307$, $\eta_p^2 = 0.072$). Nevertheless, to help comparability reaction times to the change positions 1/2, 5/6 and 3/4 are plotted in different figures (see figure 40 lower row). As can be seen in the lower row of figure 40 there seems to be only a slight trend for slower reaction times to the random blocks for change positions 1/2 and 5/6, whereas this is not the case for change positions 3 and 4. Post-hoc tests of the block effect showed a significant decrease from learning block 3/4 to random blocks 5/6 (t (16) = 2.58, p = 0.020) and a significant decrease from learning blocks 3/4 to test blocks 7/8 (t (16) = 4.51, p < 0.001).

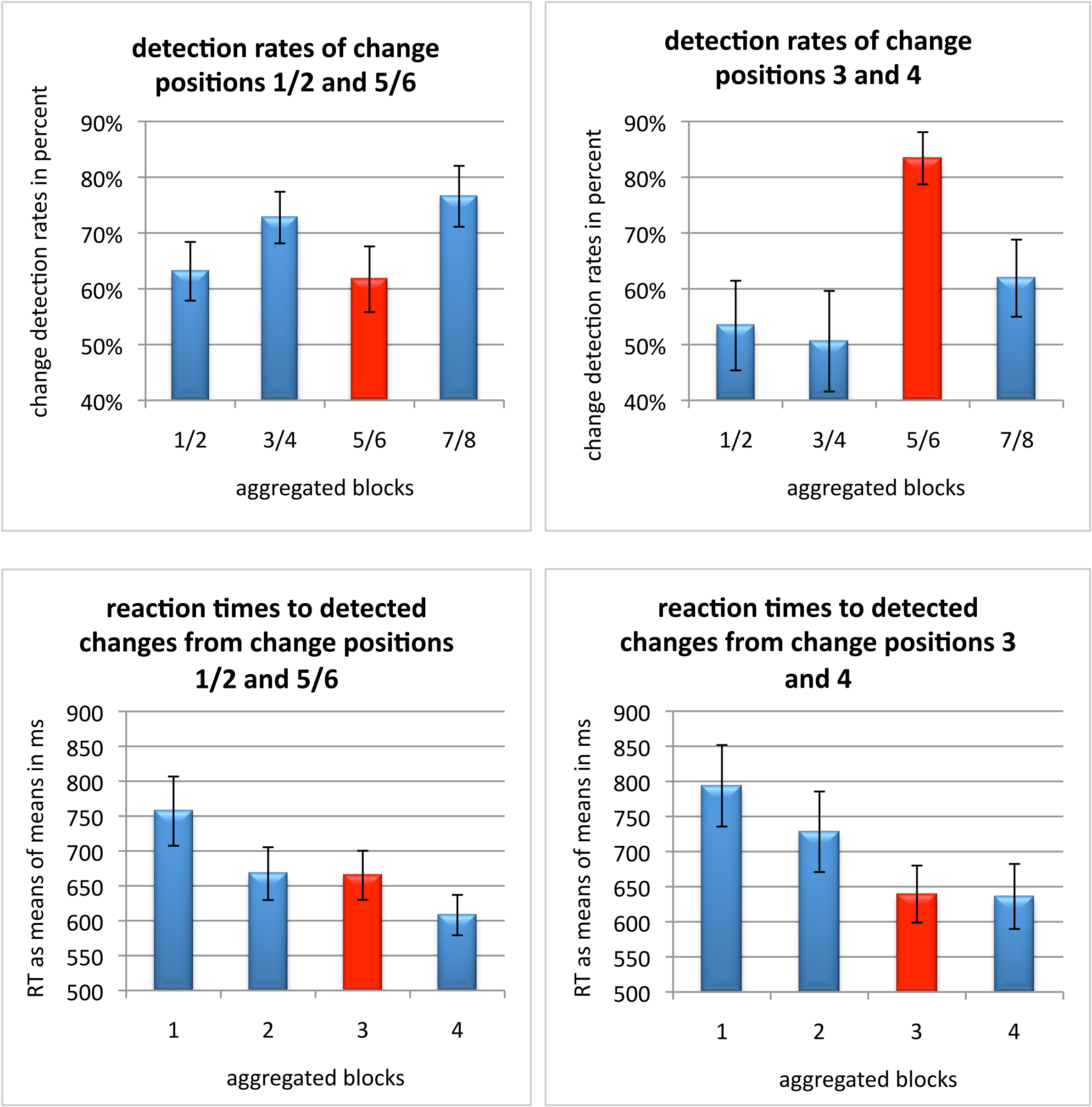


Figure 40. Upper row: Change detection rates (in percent) with standard errors as error bars obtained in the different blocks for change positions 1/2 and 5/6 (left side) and change positions 3/4 (right side). Lower row: Reaction times to detected changes (in ms) with standard errors as error bars obtained in the different blocks for change positions 1/2 and 5/6 (left side) and change positions 3/4 (right side).

The effect of semantic contextual cueing on visual search

ERP Data:

As stated in the introductory section of the fifth experiment, it was hypothesized that the exogenous contextual cue might influence attentional capture in the pre-change image when learned. None of the ERP components, however, was modulated by block or change positions in the pre-change scene (see figure 41). Therefore the analyses concerning the change detection task concentrate on the post-change scene.

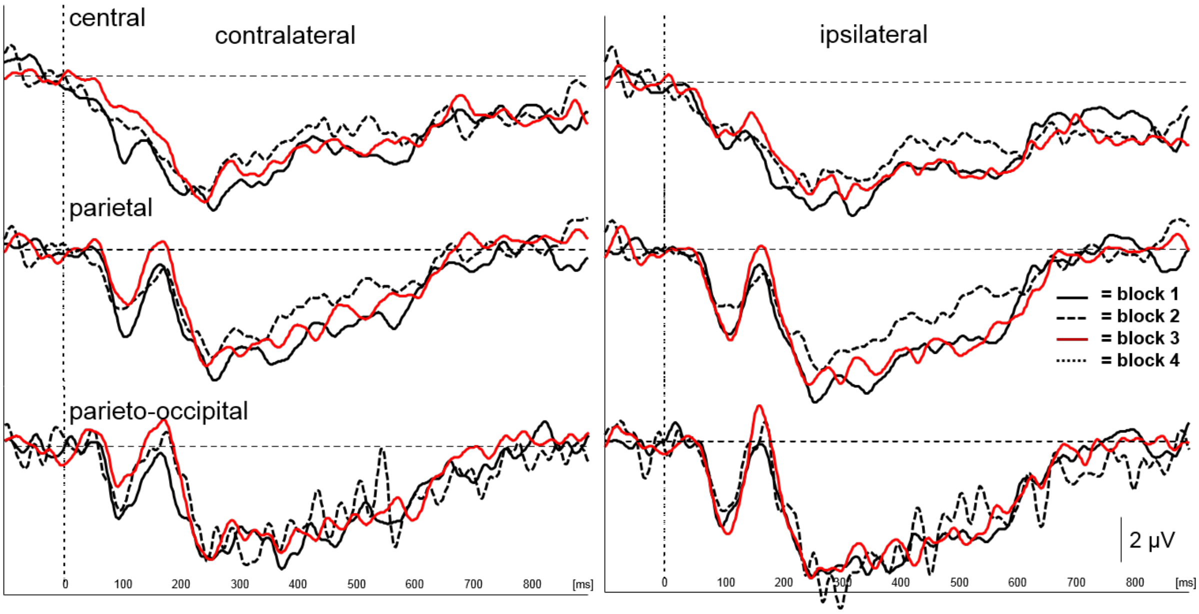


Figure 41. Grand averages of the pre-change image for the aggregated learning blocks (3 and 4), the random blocks (5 and 6) and the test blocks (7 and 8) at the ipsilateral (a) and contralateral (b) central, parietal and parieto-occipital electrodes. Continuous lines are changes in the first block; dashed lines are changes in the second block; red continuous lines are changes in the third block and dotted lines are changes in the fourth block.

Grand-averages of the post-change image for the blocks seem to show an enhancement of P1 amplitude for the random blocks and a differentiated block effect in the

P3 time interval (see figure 42). Here a kind of linear effect with time can be seen with an increase from learning to random and test blocks.

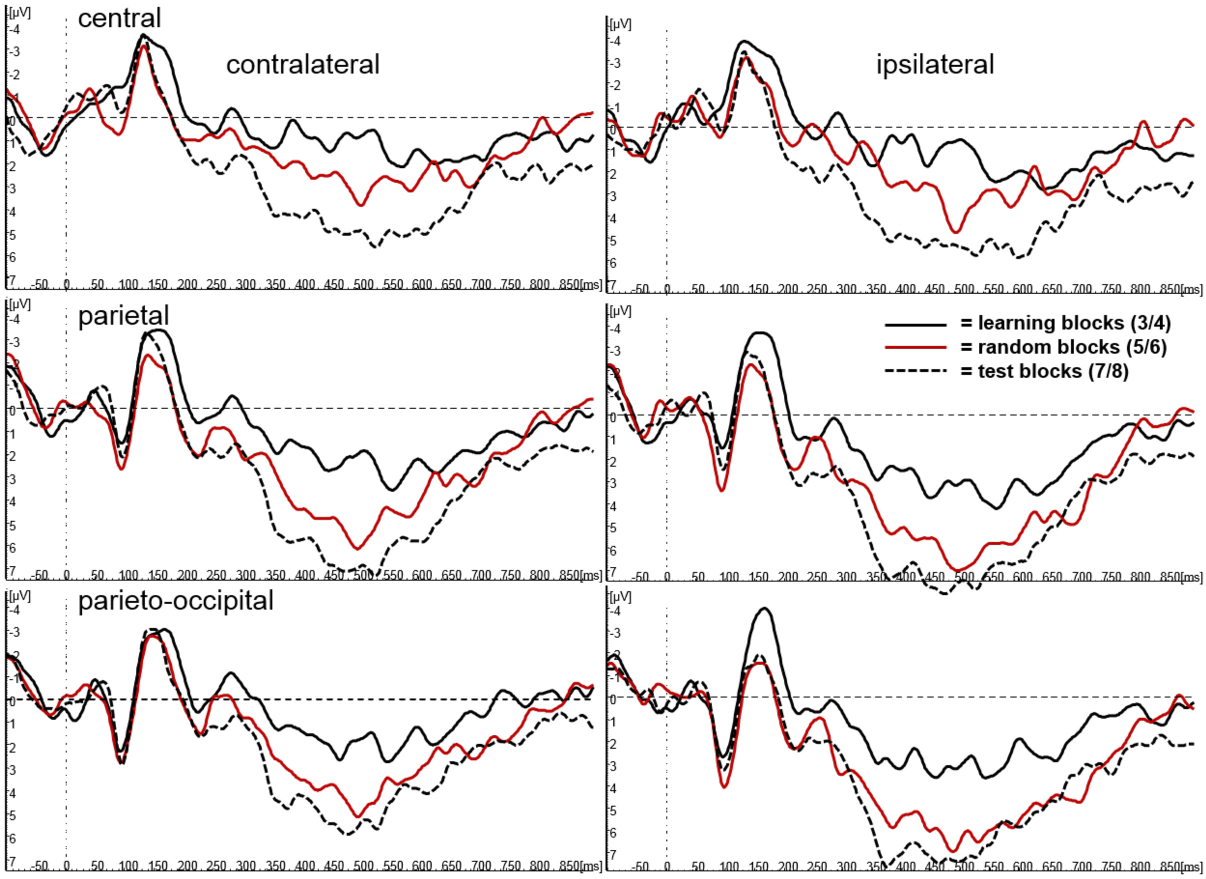


Figure 42. Grand averages of the post-change image for the aggregated learning blocks (block 3 and 4), the random blocks (5 and 6) and the test blocks (7 and 8) at the ipsilateral (a) and contralateral (b) central, parietal and parieto-occipital electrodes. Continuous lines are changes in the learning blocks; red continuous lines are changes in the random blocks; dashed lines are changes in the test blocks.

The repeated measures analysis of variance (ANOVA) for the P1 time interval (80-110 ms) with the factors change positions, block, and electrode revealed significant main effects of block (F (2, 32) = 5.24, p = .013, η_p^2 = 0.247) and electrode (F (5, 80) = 16.64, p < .001, η_p^2 = 0.510). No further significant effects or interactions could be found for block*change positions (F (2, 32) = 1.42, p = .257, η_p^2 = 0.082), block*change positions*electrode (*F* (10, 160) = 2.2, $p = .078$, $\eta_p^2 = 0.121$) or any other effects or interactions (*F*s < 1). Following the visual inspection of the grand averages the effect of block should be derived through a significant increase of amplitude in the random blocks. The pairwise t-tests comparing the learning blocks 3/4 (previous to the random blocks) with the random blocks however show no significant difference (t (16) = -1.47, $p = 0.161$). Nevertheless, the comparison of the random blocks with the test blocks shows a significant difference (t (16) = 2.48, $p = 0.025$).

As in the former experiments it could be informative to analyse the effect of hemisphere. Therefore change positions 1/2 and 5/6 are again analysed with the factors block, hemisphere (ipsilateral vs. contralateral) and electrode (as stated above change positions 3 and 4 cannot be analysed according to hemisphere). The repeated measures ANOVA showed only a significant effect of electrode (*F* (2, 32) = 14.73, $p < .001$, $\eta_p^2 = 0.513$) but no effect of block (*F* (2, 32) = 1.98, $p = .165$, $\eta_p^2 = 0.124$) or hemisphere (*F* (2, 32) = 2.55, $p = .132$, $\eta_p^2 = 0.154$) or any interaction (block*electrode: *F* (4, 64) = 2.01, $p = .148$, $\eta_p^2 = 0.125$, block*electrode*hemisphere: *F* (4, 64) = 2.62, $p = .084$, $\eta_p^2 = 0.158$, all other interactions: *F*s < 1).

The repeated measures ANOVA in the N1 time range (150-180 ms) showed no effect at all (change positions: *F* (1, 16) = 2.62, $p = .152$, $\eta_p^2 = 0.141$, block: *F* (2, 32) = 2.13, $p = .124$, $\eta_p^2 = 0.117$, change positions*block: *F* (2, 32) = 1.17, $p = .328$, $\eta_p^2 = 0.068$, all other effects or interactions: *F*s < 1).

The ANOVA considering hemisphere, however, revealed a significant interaction of block*hemisphere (*F* (2, 32) = 3.85, $p = .034$, $\eta_p^2 = 0.216$) as well as the three way interaction for block*hemisphere*electrode (*F* (4, 64) = 7.18, $p = .001$, $\eta_p^2 = 0.339$). The interaction is due to a significant decrease of the N1 from learning to random blocks at central leads contralateral to the change and at parieto-occipital leads ipsilateral to the change (see table 3). No further significant effects or interactions in the ANOVA could be found for block (F (2, 32) = 2.95, p = .072, η_p^2 = 0.174), electrode*hemisphere (F (2, 32) = 1.53, p = .239, η_p^2 = 0.098) or any other effects or interactions (Fs < 1).

Table 3

Pairwise t-tests comparing the aggregated blocks of change positions 1/2 and 5/6 and aggregated blocks at a) central leads ipsilateral to the change and b) parieto-occipital leads contralateral to the change in the N1 time range

a) aggregated block of change positions 1/2 and 5/6		T	df	significance (two-tailed)
3/4	5/6	-3,395	16	,004
5/6	7/8	,250	16	,805
b) aggregated blocks at central leads ipsilateral to the change		**T**	**df**	**significance (two-tailed)**
3/4	5/6	-4,633	16	,000
5/6	7/8	,712	16	,487
c) aggregated blocks at parieto-occipital leads contralateral to the change		**T**	**df**	**significance (two-tailed)**
3/4	5/6	-3,596	16	,002
5/6	7/8	,055	16	,957

The analysis for the N2pc effect (240-310 ms) showed only a main effect of electrode (F (5, 80) = 4.2, p = .015, η_p^2 = 0.208) but no other significant effects or interactions for block (F (2, 32) = 1.08, p = .351, η_p^2 = 0.063), change positions*electrode (F (5, 80) = 1.72, p = .180, η_p^2 = 0.097), block*electrode (F (10, 160) = 2.01, p = .079, η_p^2 = 0.112) or any other effects or interactions (Fs < 1).

The repeated measures ANOVA considering hemisphere showed a significant main effect of hemisphere (F (1, 16) = 5.69, p = .030, η_p^2 = 0.262) with higher amplitudes contralateral to the change as well as a significant interaction of hemisphere*electrode (F (2, 32) = 6.04, p = .016, η_p^2 = 0.274). Post hoc tests revealed that the significant increase of amplitude contralateral to the change is especially pronounced at parietal (t (16) = -2.37, p = 0.031) and parieto-occipital leads (t (16) = -2.77, p = 0.014). No further significant effects or interactions could be found for block (F (2, 32) = 2.2, p = .135, η_p^2 = 0.121), electrode (F (2, 32) = 2.38, p = .121, η_p^2 = 0.129), block*electrode (F (4, 64) = 1.14, p = .341, η_p^2 = 0.067), block*hemisphere (F < 1), and block*hemisphere*electrode (F (4, 64) = 1.68, p = .182, η_p^2 = 0.095).

The repeated measures ANOVA for the P3 time interval (350-550 ms) resulted in significant main effects of block (F (2, 32) = 7.55, p = .002, η_p^2 = 0.320) and electrode (F (5, 80) = 13.71, p < .001, η_p^2 = 0.461) as well as a significant interaction for change positions*block (F (2, 32) = 4.23, p = .026, η_p^2 = 0.209). No further significant effects or interactions could be found for change positions*electrode (F (5, 80) = 1.96, p = .129, η_p^2 = 0.109), block*electrode (F (10, 160) = 1.95, p = .097, η_p^2 = 0.109), and block*change positions*electrode (F (10, 160) = 1.07, p = .383, η_p^2 = 0.063).

The block effect is due to a significant increase from learning to random blocks (t (16) = -2.23, p = 0.041) but the increase from random to test blocks is not significant (t (16) = -1.7, p = 0.109). Nevertheless the increase from learning to test block is significant (t (16) = -3.72, p = 0.002). Due to the interaction with change positions separate ANOVAs for change positions 1/2, 5/6 and change positions 3/4 are done. The ANOVA for change positions 3 and 4 showed no effects of block or interaction of any factor with block.

The ANOVA for change positions 1/2 and 5/6 considering hemisphere also showed a main effect of block (*F* (2, 32) = 9.08, p = .001, η_p^2 = 0.393) as well as main effects of electrode and hemisphere (*F* (1, 16) = 5.15, p = .040, η_p^2 = 0.269) with an increased P3 amplitude ipsilateral to the change. The post-hoc tests show the described linear increase from learning blocks 3 and 4 to random blocks 5 and 6 and a not significant trend for an increase from the random blocks to the test blocks 7 and 8 as well as an significant increase from learning to test blocks (table x4.

Table 4

a) Pairwise t-tests comparing the aggregated blocks of change positions 1/2 and 5/6 in the P3 time range

b) Mean amplitudes in the aggregated blocks of change positions 1/2 and 5/6 in the P3 time range

a) aggregated blocks of change positions 1/2 and 5/6		T	df	significance (two-tailed)	b) aggregated blocks of change positions 1/2 and 5/6	mean amplitude in mV
3/4	5/6	-2,334	16	,033	3/4	1,901
5/6	7/8	-1,781	16	,094	5/6	4,074
3/4	7/8	-4,500	16	,000	7/8	5,617

Repetition priming effects - the semantic contextual cueing design facilitates the stability of visual representations

Behavioural Data:

The analyses concerning the repetition-priming task revealed no difference according to change positions or block. This lack of effects is seen for the recognition rates (*F*s < 1) as well as the reaction times (block: $F\ (2, 32) = 1.2$, $p = .318$, $\eta_p^2 = 0.107$, change positions and the interaction: *F*s < 1). Furthermore the same is true if change detection is taken into consideration (recognition rates: block*change detection ($F\ (2, 32) = 1.27$, $p = .292$, $\eta_p^2 = 0.074$), detection rates: block*change detection ($F\ (2, 32) = 3.42$, $p = .055$, $\eta_p^2 = 0.176$), all other effects (*F*s < 1). This can also be seen in the graphs of figure 43.

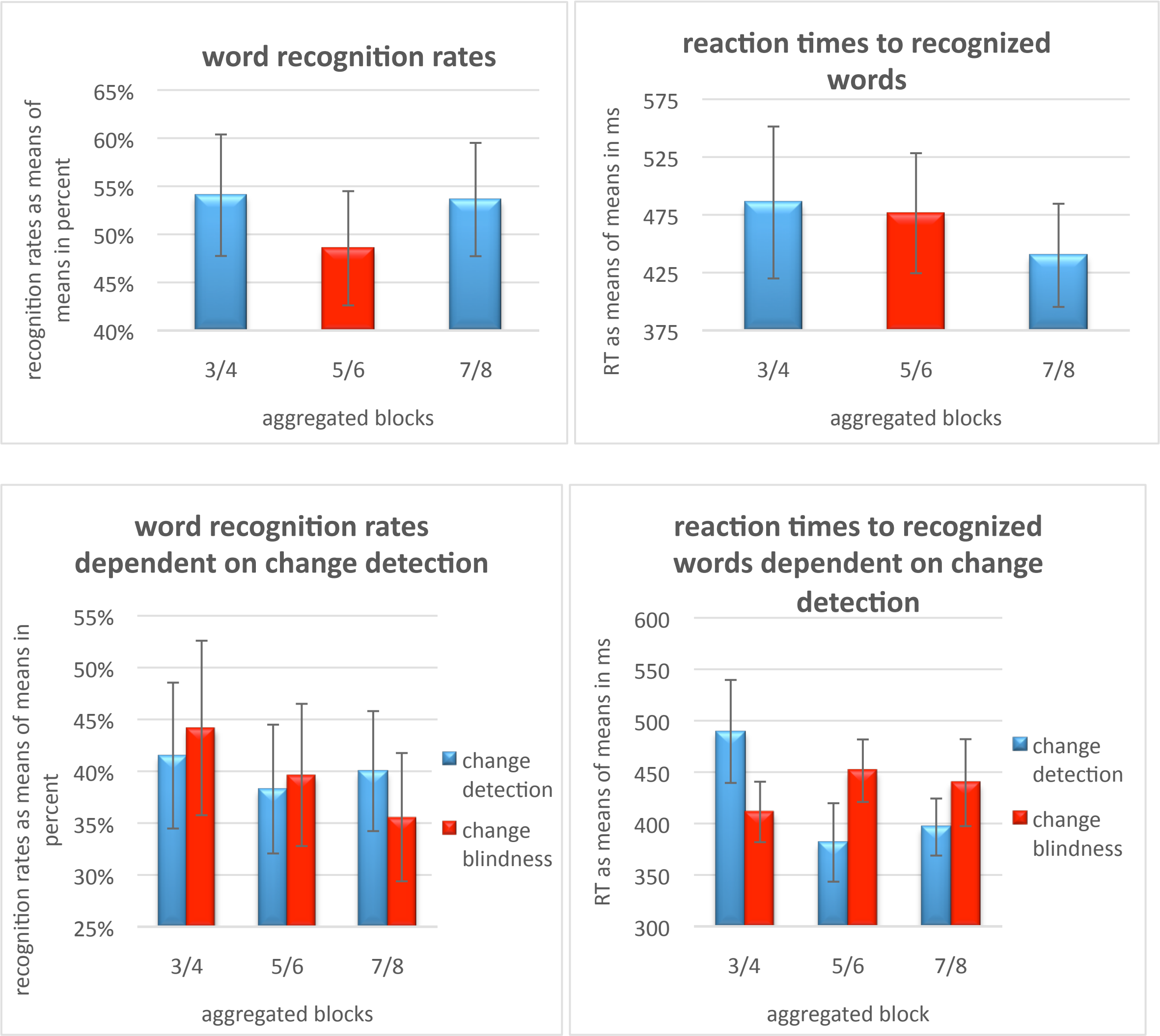


Figure 43. Upper row - left side: Word recognition rates (in percent) with standard errors as error bars obtained in learning and test blocks (blue bars) and random blocks (red bars). Right side: Reaction times to recognized words (in ms) with standard errors as error bars

obtained for recognized words in the learning and test blocks (blue bars) and random blocks (red bars). Lower row - Left side: Word recognition rates (in percent) with standard errors as error bars obtained in learning, random and test blocks dependent on change detection (blue bars) and change blindness (red bars). Right side: Reaction times to recognized words (in ms) with standard errors as error bars obtained in learning, random and test blocks dependent on change detection (blue bars) and change blindness (red bars).

The semantic contextual cueing design facilitates the stability of visual representations

ERP Data:

The ERP data for the word task were analysed according to the N4 time range. Although no effect of block or change positions could be found in the behavioural data, the ERP data might be more sensitive to learning effects. Due to the fact that in the repetition priming task the N400 is to be analysed, only non-detection trials are included. In these trials no button press was required and therefore the average is not overlaid with the motor response. The visual inspection of the grand averages seems to show a N4 effect at central electrodes and a P3 effect at parietal and parieto-occipital electrodes (figure 44).

The repeated measures ANOVA for the N4/P3 time interval (300-500 ms) resulted – analogous to the behavioural data – in no effect of block or change positions and only a significant main effect of electrode (F (5, 80) = 10.9, $p < .001$, $\eta_p^2 = 0.456$) could be found (all other effects or interactions: Fs < 1).

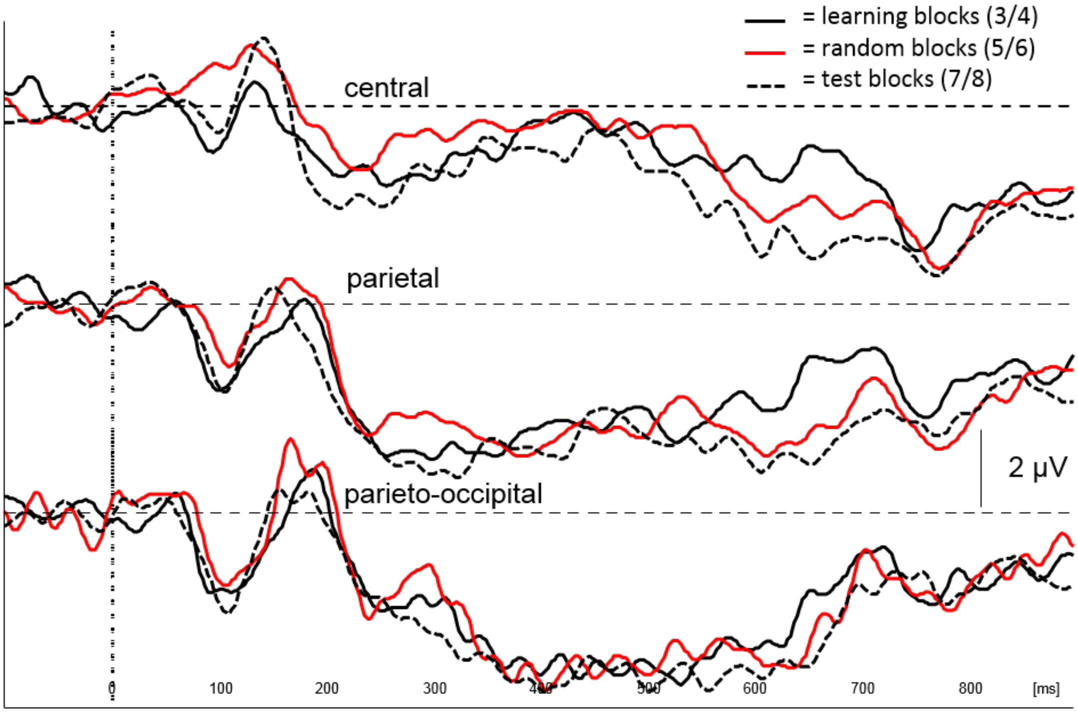


Figure 44. Grand averages for the effect of block on the target word at central, parietal and parieto-occipital electrodes. Black continuous lines are the averaged learning blocks (3 and 4); red continuous lines are the averaged random blocks (5 and 6) and black dashed lines are the averaged test blocks (7 and 8).

Discussion

Summary

The fifth experiment showed signs of a learning effect for exogenous contextual cues in the change detection rates but not the reaction times, which only showed a practice effect. The ERP components mirror the behavioural data with signs for a learning effect in the early component P1 and partly in N1 induced by the random blocks and a more linear practice effect in the P3 time interval. These effects however are only found in the post- but not the pre-change scene. Furthermore, as in previous experiments there is an unspecific change effect in the N2pc and P3 time range.

The predictability of the exogenous contextual cues did not affect repetition priming. The stability of representations is not influenced by the possibility to predict the change positions. The same lack of a modulation from learning on the stability of representations can be seen in the analyses of event related potentials in the N4 time interval.

The effect of semantic contextual cueing on visual search - behavioural data

The change detection rates differ according to the change positions that are predicted by the exogenous semantic contextual cues. The recognition rates to the predicted change positions 1/2 and 5/6 show a decrease from predictable to random blocks. The recognition rates to the predicted change positions 3/4 show the reversed pattern: an increase from predictable to random blocks. Reaction times showed a linear decrease with time throughout all change positions. It therefore seems at first clear that the design was successful in providing a learning possibility to reduce change blindness. This, however, is only true for the recognition rates to the predicted change positions 1/2 and 5/6. Why do the different change position pairs result in different change detection patterns? One explanation for the results to change positions 3/4 under the assumption of successful learning may be that the items in the lowest positions of the visual display are processed differently. Studies who found a differentiated processing of the lower visual field, however, claim a benefit for the processing of items in the lower hemifield (He, Cavanagh, & Intriligator, 1996; Rubin, Nakayama, & Shapley, 1996). If there is enhanced processing of items in the lower visual field, the results from reactions to the predicted change positions 3/4 should show a pronounced drop in detection rates in the random blocks. The probability for the change to take place in the lower visual field is reduced in the random blocks and therefore performance should decline. Nevertheless, the reverse is true in the data for change positions 3/4. If items in the lower field are processed differently, it does not seem to be beneficially in the present experiment.

Another explanation could be an interference effect from beneficial processing of the lower field and the predicted change positions. If the lower hemifield is processed preferentially (He et al., 1996; Rubin et al., 1996) but the implicit learning of the relationship between category and change positions draws resources away from the lower hemifield in two thirds of the trials an interference may arise. If the participants learned the predictability of category for change positions their attention is mostly captured to the upper or middle visual field and it is therefore disadvantageous to preferentially process the lower hemifield. If learning was successful the processing of the lower hemifield must be suppressed to a certain degree. This should influence the reactions to change positions 3/4 in which the lower hemifield has to be attended to find the change. The suppression of the preferential processing of the lower hemifield should reduce the detection rates in the predictable blocks. In the random blocks the interference between learned predictability and hemifield processing dissolves. In these blocks the change detection should rise. This is exactly the pattern of results found in the experiment.

Nevertheless there is also an alternative explanation for the found results not relying on (implicit) learning. In contrast to previous experiments the exogenous cue was not embedded in the pre- and post-change scenes but constructed by the context. In these experiments the exogenous cue can be detected by parallel search (A. M. Treisman, 1985; Treisman & Gelade, 1980; Treisman & Gormican, 1988). In the first two experiments single letters are chunked into an exogenous lexical semantic cue and pop out from the surrounding single independent letters. In the third and fourth experiment the semantic and perceptual deviants serve as a pop out. In the present experiment however the exogenous cue is the semantic context of all presented stimuli. Parallel search could therefore not take place and participants had to fall back to serial search (A. M. Treisman, 1985; Treisman & Gelade, 1980; Treisman & Gormican, 1988). When confronted with a serial search task, participants tend to search in reading direction with a scanning pattern from left to right and from the upper to the lower hemifield (Chokron & DeAgostini, 1995; Vaid & Singh, 1989). For the present experiment this would mean that participants most probably searched positions 6 – 1 – 5 – 2 – 3 – 4. Given the limited time, this serial search pattern would result in higher detection rates for changes at positions searched first (1/2 and 5/6). The comparison of the results for change positions 1/2 and 5/6 vs. ¾ shows higher detection rates in the predictable blocks for change positions 1/2 and 5/6. In the random blocks the change position can be any of the six positions irrespective of the presented categories. Therefore fewer changes are at change positions 1/2 and 5/6 in the random blocks for the categories usually predicting these change positions and the detection rate is reduced. For the category predicting change positions 3 and 4 the reversed effect could be seen with an increase in detection for the random blocks. This can again be explained with serial search direction. Fewer changes could be detected when the positions are searched last in the predictable blocks. In the random blocks however the probability of change positions is equal for all possible positions and therefore the earlier searched positions increase change detection.

This serial search hypothesis is also able to explain the linear decrease in reaction times where an increase in reaction times in the random blocks was expected. If subjects were not influenced by the predictability relation between category and change positions and searched serially through the scenes no difference is to be expected between learning, random and test blocks. The reaction times should only show a practice effect with a gain in speed over time. The trend for slightly higher reaction times in random blocks seen in the graphs for change positions 1/2 and 5/6 might just be a response to the lower change detection rates. This drop in detection performance might be an expectation violation and therefore slows the reaction times down to a certain degree (Nissen et al., 1987). Nevertheless the analyses show a monotonous decrease in reaction times over blocks.

ERP results influenced by semantic contextual cueing

Pre-change scene.

In contrast to the hypothesis, the pre-change scene did not show attentional shifts to the predicted change positions. As seen in the previous experiments, the context is efficient if it can be categorized and be formed into a standard previous to change detection. Therefore the context might be categorized and forms the standard in the pre-change scene that is then used as an exogenous cue for the post-change scene. This assumption might explain the lack of attentional shifts to the predicted change positions in the pre-change scene.

Post-change scene.

The early ERP components showed differentiated reactions to the random blocks for the post-change scene. The P1 was increased in the random blocks as compared to the test blocks whereas the N1 (for change positions 1/2 and 5/6) was reduced by these blocks as compared to the learning blocks. The late component P3 showed a relative stable linear effect with an increase from blocks 3/4 to the random blocks 5/6 and the test blocks 7/8.

It seems that the early visual processing is more sensitive to predictability of change positions from category than late components. The P1 reflects sensory gating to attended items (Eimer, 1993; Luck & Hillyard, 1994). Predictable blocks should draw attention to the change positions predicted by the present category whereas in the random blocks the subjects have no cue on which change position the change will occur. Nevertheless a higher P1 is found in the random blocks. According to Luck & Hillyard (1995) the P1 component reflects an attentional process which suppresses distracter items. In the random blocks all six drawings have to be attended to and therefore five distracters are present. In the predictable blocks only two items have to be attended (if the connection between category and change positions is learned) and therefore only one distracter is present. This explanation accounts for the facilitation of the P1 in random blocks as compared to the test blocks where the predictive relationship is reinstated.

In the N1 time interval the picture is reversed with a reduction of amplitude in random blocks for change positions 1/2 and 5/6. Vogel and Luck (2000) found that the N1 reflects a discrimination effect of attended stimuli and enhanced processing of attended stimuli. In contrast to the P1, the N1 component is not associated with suppression of stimuli outside the focus of attention or when attention is distributed (Luck & Hillyard, 1994, 1995). In the learning and test blocks only two stimuli have to be attended and therefore should elicit a stronger N1 than in the random blocks in which attention has to be distributed between six stimuli. This reduction in response to a more distributed attention seems to be true for the switch from learning blocks to random blocks.

It is however important to note that the analyses considering laterality effects are confounded with the difference between reactions to the different predicted change positions as was found in the behavioural data. In the analyses for laterality effects only the change position pairs 1/2 and 5/6 are included because the change position pair 3/4 spans both hemispheres. Nevertheless, the change positions 1/2 and 5/6 show differentiated reactions in contrast to change positions 3 and 4. Thus the analyses are likely to be confounded with the differentiated responses to the change position pairs. This confounding will be taken into account later on.

The P3 shows a linear increase with time from blocks 3/4 over blocks 5/6 to blocks 7/8. This could be due to the fact, that the P3 not only reflects awareness and detection (Koivisto et al., 2009; Koivisto & Revonsuo, 2003) but also decision processes. The P3 increase over time mirrors the reaction time pattern. This relationship between the P3 component and reaction time data is known from studies that consider confidence judgements of decisions (Eimer & Mazza, 2005; Kutas & Van Petten, 1994; Mitroff et al., 2002). These studies showed that high confident decisions were done faster and elicited higher P3 responses than low confident decisions. Therefore it is likely that over the course of the experiment participants were more confident in their decisions due to practice effects or familiarity with the experimental situation, which was expressed in an increase of reaction speed and P3 amplitude. It is quite interesting that the P3 does not vary with the predictability of the category because this component is also known to reflect information processing of categorized stimuli (Duncan-Johnson & Donchin, 1982). However it is quite clear that the monotonous increase is not sensitive to the predictability of the categories but seems to show a practice effect. The practice effect seems also to be confounded with the change position pairs. This can be concluded from the fact that the effect is found in the analyses for change positions 1/2 and 5/6 but not for change positions 3/4.

Can the results found in the ERP data be explained by the above stated serial search hypothesis as well? The P3 component found here seems to reflect a practice effect with higher amplitudes for later blocks in which the participants show higher detection rates and therefore more awareness for the change. Although this component does vary with the factor change positions the found monotonous increase over time does seem to be independent from either learning or the proposed visual search strategy.

The P1 component on the other hand clearly varies with the predictability of the blocks but not with change positions. But according to the serial search strategy the P1 should show reduced amplitudes for predictable blocks from change positions 1/2, 5/6 and random blocks from change positions 3/4. In these configurations the focus of attention (which should follow the reading direction) would find the changed item earlier and therefore fewer distracters have to be suppressed. However, no effect of change positions could be found in the P1 time interval and therefore no differentiated processing according to the different change position pairs. Nevertheless, one could argue that this effect might be present but the reduction in the random blocks from change positions 3/4 is superimposed by the enhancement in these blocks from change positions 1/2 and 5/6.

The N1 is reduced in the random blocks in the analyses considering hemisphere. These analyses can only be made for change positions 1/2 and 5/6 and therefore vary are confounded with this factor. The results found in this time interval can be explained by the serial search strategy. In the predictable blocks from change positions 1/2 and 5/6 only the first four items in reading direction (6 – 1 – 5 – 2) have to be searched to find the changed item which processing is then facilitated (mirrored in enhanced activity in the N1 component). In the random blocks the probability of the change being present in the first four items is reduced. The serial shift in the focus of attention according to reading direction cannot be stopped as early as in the predictable blocks and the facilitation of processing might not be done before the post-change image is terminated. This might lead to reduced activation in the N1 component due to the stronger attention distribution.

Implicit learning vs. serial search

Did the participants in the fifth experiment learn the predictability of the categories for the change positions or did they search serially in reading direction? The behavioural data from the detection task might point either to implicit learning or to the serial search strategy. The change detection results of change positions 1/2 and 5/6 can be interpreted as signs of implicit learning or implicit knowledge. The detection results of change positions 3/4 are not easily compatible with the expected results from implicit learning and need an interference approach to be explained in terms of implicit learning. Therefore, the serial search strategy seems to be a parsimonious explanation that can account the behavioural results of change positions 3 and 4. The reaction time data does not show any sign of learning except a slight not significant trend for a slowing of reaction times in random blocks for change positions 1/2 and 5/6. They rather seem to express a practice effect with a relatively linear speeding of reaction times over time. Therefore the ERP data are needed to shed light on this question. The early component P1 is in favour of implicit learning in that it shows differentiated processing of the random blocks independent of the change position pairs. According to the serial search strategy the processing of change positions 1/2, 5/6 and 3/4 should show contrary results. The N1 did show a differentiated processing of random blocks only for change positions 1/2 and 5/6 in the analysis considering hemisphere. These results are compatible with both explanations. The late component P3 on the other hand mirrors the reaction time results with a more linear, monotonous effect over time and therefore does not speak for either implicit learning or serial search.

Reber (1989) has found that a structured environment leads to the use of that attribute of the environment to reduce resources needed for the task at hand. In the present experiment this should be the predictability of category for change positions. The structuring of information in meaningful or predictive units seems to be a basal attribute of information processing (Biederman et al., 1982; Boyce, Pollatsek, & Rayner, 1989; Gibson, 1966; Gobet et al., 2001; Miller, 1956; Simon, 1974; Stadler & Frensch, 1994). Especially the literature on implicit learning seems to show that the human system is predestined to use all available information to reduce resources and accomplish a task albeit the wide variety of paradigms/situations in which implicit learning was tested (Frensch et al., 1998; Knopman & Nissen, 1987; Reber, 1967; Tillmann, Bharucha, & Bigand, 2000; Willingham, Nissen, & Bullemer, 1989). In the present experiment the contextual cueing paradigm (Chun & Jiang, 1998) was adopted to a semantic invariant context albeit with variant specific stimuli. Furthermore the category does cue two possible change positions thereby somewhat reducing the predictability. In other words, as compared to the contextual cueing paradigm the present experiment constituted a rather difficult learning paradigm. This might explain the mixed results. Nevertheless, considering the amount of evidence for the prevalence of implicit learning in structured contexts, it is reasonable to assume, that the implicit learning strategy is more likely than the serial search strategy.

It could very well be that the present experiment is too short for more clearly expressed signs of learning in a semantic contextual cueing paradigm. The blocks contained only 18 trials and therefore learning had to be done over 72 trials. This might be too short for the effect to be expressed in the reaction times and late ERP components. Behavioural pilot studies for the fifth experiment confirmed that a learning effect begins after 70 trials. Nevertheless, for the implicit learning effect to influence confidence that mediates reaction times and the P3 component it might have to be more stable. Thus it seems that a consolidation phase is necessary between the learning of the predictive relationship and the destruction of the predictability in the random blocks. Hence future research of the semantic contextual cueing paradigm should provide a longer learning phase.

ERP effects induced by unspecific changes

Replicating the effect of an unspecific change in the third and fourth experiment, the P3 is again enhanced ipsilateral to the change irrespective of the semantic contextual cueing, as is the N2pc contralateral to the change. Thus it might again be that the change itself serves as a local mismatch to the stored representation of the pre-change scene.

As explained in the discussions to the third and fourth experiment, the ipsilateral evoked P3 seems to reflect an attentional mechanism to detect mismatches (Fernandez-Duque et al., 2003; Hillyard & Münte, 1984; Niedeggen et al., 2001; Skrandies, 1983) and the N2pc mirrors attentional shifts with higher amplitudes contralateral to the attended items (Luck & Hillyard, 1994; Luck et al., 2000; Schankin & Wascher, 2007, 2008). Both components thus rely on attention to be captured by the change which should be possible if the pre- and post-change scene representations are compared or the attention is by chance on the region containing the change. The fact that components reflecting attention allocation and mismatch detection are continuously evoked by unspecific changes speaks against an effect mediated by chance and for an attentional detection mechanism targeted on change detection.

The semantic contextual cueing design facilitates the stability of visual representations

It was proposed that the stability of visual representations should increase with the possibility to detect the change positions as predicted by the category and decrease in the random blocks were no regularity supports the allocation of attention. This however could not be confirmed in the behavioural or electrophysiological data of the repetition priming task. In both analyses no differentiated effect for the random as compared with the learning and test blocks could be found.

Two conclusions could be drawn from this lack of any effect of semantic contextual cueing on the stability of visual representations. First, it might be that learning did not take place and the serial search strategy assumption is right. If the relationship between category and predicted change positions is not learned the stability of visual representations should not be increased in blocks with the predictable relationship between category and change positions as well as not decreased in the random blocks. Thus explaining the lack of modulation by block in the analyses. Second, it may be that learning itself does not modulate the stability of representations. This however is relatively unlikely given that the learning of the predictable relationship should draw attention to the predicted change positions, which enhances the stability of visual representations (Schmidt et al., 2002). Therefore the lack of a modulation of visual representation stability by the predictability of the relationship between category and change positions seems to be an argument against successful learning in the present experiment. Given the results of the detection rates and early ERP components a third possibility seems likely. As argued above it might be that the experiment was too short to ensure stable implicit learning of form stable implicit knowledge. Therefore although learning took place to a certain amount this might not be enough to influence the stability of visual representations. Again, a longer experiment might clear if learning can influence the stability of visual representations.

Conclusion

The fifth experiment shows signs for semantic contextual cueing in detection rates and early ERP components. Nevertheless the results can also be brought in line with a serial search strategy. This strategy is supported by the lack of learning signs in the reaction times and P3 modulation as well as the lack of a semantic contextual cueing effect on the stability of representations as seen in the behavioural and electrophysiological data. It can however not be ruled out that the lack of stable signs for semantic contextual cueing is due to the shortness of the experiment.

General discussion

The range of experiments reported here show that exogenous cues that are not overtly task relevant but are capable to alleviate task performance are processed and facilitate visual search. This visual search facilitation of not instructed cues could be seen for perceptual, semantic and in part for semantic contextual cues.

The first two experiments show that exogenous lexical semantic cues are processed in a visual search task depending on the mode of processing (explicit vs. implicit). Explicit processing is dependent on task relevance and reduces change blindness. This is not the case for implicitly processed cues. Nevertheless, explicit and implicitly processed lexical semantic cues show a priming effect in the ERP data and thus are able to form stable representations. Although it is clear that semantic exogenous cues are effective, the prior presentation of perceptual endogenous cues reduces the resources available for attentional capture by the exogenous cue and hinders the formation of stable visual representations of the lexical semantic cue as expressed in the ERP data. To compare the influence of perceptual and semantic stimuli features on visual search the third and fourth experiment used exogenous cues of both types.

Both experiments show that exogenous perceptual and semantic cues influence visual search and interact when mediated by context although perceptual deviants predominate in their influence on visual search. Depending on the position of a homogenous semantic context this interaction is expressed either on the behavioural/output level (experiment three) or the electrophysiological/processing level (experiment four). Perceptual and semantic exogenous cues are processed relatively independent and only interact when the context promotes it either on the processing or output level. The deviancy of the exogenous cue serves as a facilitator for memory processes. Recognition was enhanced by repetition priming of the scene containing the deviants and thus argue for the significance of exogenous cues for the storage of information.

In the fifth experiment the context is used as the exogenous cue and shows signs for semantic contextual cueing. Unfortunately the experiment is too short to reliably conclude on semantic contextual cueing from the results especially due to the lack of learning signs in the reaction times, the P3 component and the lack of effect on the stability of representations as found in the recognition task. An alternative assumption that explains the results of the fifth experiment is the use of a serial search strategy.

Exogenous cues in the presented experiments

The range of experimental results found for the modulation of attention and memory in the change blindness paradigm by exogenous cue might be interpreted in favour of the assumption that the use of exogenous cues is a general principle of visual search. In contrast to experimental situations, endogenous cues are the exception rather than the rule in “natural” visual search. Our information processing system might rely on exogenous cues in the form of inherent regularities of the visual environment. This is supported by studies which show the relevance of bottom-up perceptual salience of stimuli (Itti & Koch, 2000; Parkhurst et al., 2002) and top-down knowledge/expectation based salience of stimuli for visual search (Friedman, 1979; Henderson, 2003; Henderson & Ferreira, 2004; Henderson et al., 1999).

The first two experiments further supported this generality assumption by the fact that exogenous cues are processed not only explicitly but also implicitly. Implicit processing is thought to be evidence for processing without consciousness (Dehaene & Naccache, 2001) that is effortless, fast, and cannot easily be controlled (Hasher & Zacks, 1979). This unintentional processing is a strong indicator for the role of exogenous cues for visual search. Cues that are processed without conscious control and are able to guide the allocation of attention seem to be of general importance for visual search. Another indicator is the variety of exogenous cues that are able to facilitate visual search. Not only perceptual cues are able to exogenously capture attention to enhance detection performance in a visual search paradigm but also semantic and even semantic contextual cues. The connecting element between these variations of exogenous cues is the context of the visual scene. As was shown by the third and fourth experiment the context mediated the interaction of semantic and perceptual cues. If a context was present semantic cues facilitated the effect of perceptual cues. If, on the other hand, the context was not present or could not be formed both cues acted independently on visual search. Nevertheless, the context not only mediates the effect of exogenous cues but also can be the exogenous cue. As Chun and Jiang (1998) showed in their studies on perceptual contextual cueing, the repeated presentation of a spatial layout cues target location and enhances detection. In the fifth experiment it was shown in a couple of markers that this might also be achieved with a semantic context. Therefore exogenous cues regardless of their stimulus format might generally guide visual search.

The influence of exogenous cues on visual memory

Further evidence for the generality assumption of exogenous cue guidance is the facilitation of representations by the presence of task relevant exogenous cues as seen in experiments three and four. Therefore it is clear that exogenous cues are not only processed explicitly and implicitly but influence the storage of information and the allocation of attention leading to enhanced detection.

The result that exogenous cues influence the stability of visual scene representations bears directly on the research on the change blindness phenomenon. To assure change detection it is necessary to form a representation of the pre-change scene (or parts of the pre-change scene) and to compare this representation with the post-change scene (or parts of the post-change scene). Thus, the underlying mechanism of change blindness might be the transiency of visual information as described in Rensink's coherence theory (Rensink, 2000, 2002). This theory, as explained in the introduction, assumes that visual information is only coherently represented when in the focus of attention. Therefore, when the post-change scene is presented, change detection is only possible for the part of the scene currently attended because for that part a coherent representation from the pre-change scene is for a short time available. Hollingworth (2006) in contrast, states that information can persist and be accumulated in visual short term and visual long term memory for some time without attention although the withdrawal of attention leads to decaying memory traces. This theory is further supported by evidence by Busch (2013) who was able to show memory traces for pre- and post-change representations in the absence of change detection.

Based on these theories different explanations are possible. As explained in the introduction explanations state that change blindness might be due to representation or comparison failures. Although multiple reasons might be responsible for change blindness (Varakin et al., 2007), in the majority of change blindness studies it was concluded that the representation of the modified scene overwrites the representation of the original scene thereby creating one form of a comparison failure (overwriting hypothesis; M. R. Beck & Levin, 2003; Mäntylä & Sundström, 2004; Mitroff et al., 2004). Nevertheless, there is another explanation for the prevalence of post-change representations in these studies; Yang and Yeh (2009) proposed a retrieval blocking mechanism which relies on the recency effect (retrieval advantage for the most recent stimuli; Broadbent & Broadbent, 1981) of the post-change object which blocks the retrieval of the pre-change representation. Therefore in the course of a change blindness experiment both scenes are represented but the recency of the post-change scene leads to facilitated retrieval of the post-change representation and blocking of the retrieval of the pre-change representation. The presented experiments three and four nevertheless clearly showed that this could be modulated by cues. The position of the exogenous deviant cue in the pre- or post-change scene determined which representation was facilitated and retrieved in the word task. This is supported by studies that showed the influence of cues on the retrieval of pre- and post-change scene representations (Yang & Yeh, 2009).

Hence it is clear that exogenous cues influence the storage of visual information in the visual short and long term memory and consequently are able to overcome the retrieval blocking from the post-change scene and even block its retrieval if the exogenous cue draws attention to the pre-change scene. The exogenous cue allocates attention to a certain stimuli or position and facilitates the generation of a representation that can be stored in an abstracted representation in the visual short and long term memory. These representations can be used for retrieval and might block other representations that are not facilitated by the attention capture from the exogenous cue. The results from the third experiment show that the exogenous cue facilitates the representation of the post-change scene where the cue is located whereas in the fourth experiment the representation of the pre-change scene is facilitated because the exogenous cue is presented there.

In the fifth experiment the cue is the context, which predicts change positions and thus might facilitate the representation of the pre- and post-change cues in blocks with a predictable relationship between context and change position. Nevertheless the representations of the pre- and post-change scene are not modulated by the predictability variation in the fifth experiment. This might be due either to the fact that learning of the semantic contextual cue was not successful or that learning does not influence the stability of representations. Subsequent research might be able to clarify which reason is responsible for the lack of a modulation of visual representations by the semantic contextual cue.

Electrophysiological evidence for the effect of exogenous cues

The role of exogenous cues for the visual search is further supported by the electrophysiological data. As explained above, the mechanism underlying the role of exogenous cues is the allocation of attention to a cued stimulus/position. That attention is influenced by the exogenous cues is evident in the modulation of early ERP components associated with attention. In the third, fourth and fifth experiment exogenous cues modulated the P1 and N1. These components are said to reflect sensory gating processes for attended items (Eimer & Kiss, 2008; Luck et al., 2000; Mangun & Hillyard, 1990). Hence it is clear that attention is allocated by the exogenous cues to certain stimuli/positions. As explained above this attentional modulation is a prerequisite for the consolidation of coherent representations into visual short and long term memory, which in turn leads to detection.

The assumption that these representations are stored is also supported by the ERP data. The priming paradigm was used to research if the pre- and/or post-change scene representations are facilitated by cueing. The late ERP components P3 and N4 were used to answer these questions. Schnyer, Allen and Forster (1997) showed that implicit and explicit memory processes in repetition priming activate the N4. Wolach and Pratt (2001) showed that memory processes also modulate the P3. Both components did show facilitated memory traces for either pre- or post-change scenes depending on the direction of the retrieval blocking mechanism as modulated by the exogenous cue.

It is important to note that only implicit repetition priming was analysed to prevent motor responses from superimposing the late components. As explained in the first two experiments the modulation of the N4 varies with the consciousness of processing and the SOA between prime and target. As shown by Kiefer (2002) the modulation of the N4 by implicit processing depends on the SOAs in interaction with the difficulty of the task. Easier tasks modulate the N4 on the implicit level at longer SOAs than more difficult tasks. This is also evident in the presented studies. Even on SOAs of 1750 ms between pre-change scene prime and repetition priming target an N4 effect could be found (experiment four). Therefore the repetition priming paradigm seems to present a quite easy task whereas semantic priming does not even modulate the N4 on the implicit level on SOAs up to 500 ms in the first two experiments. This modulation of the implicit N4 depending on task demands has implications on the relation between explicit and implicit processing.

The relation of explicit and implicit processing.

Kiefer (2002) stated that implicit processing influences the N4 up to a certain SOA that varies with the task. This is supported by the differences in N4 modulation depending on semantic and repetition priming as seen in the here presented experiments. Although implicit repetition priming showed modulation of the N4 at SOAs of 1750 ms no modulation of implicit semantic priming could be found even at SOAs of 500 ms. Thus implicit and explicit processing access the same processes for a certain time span depending on the task demands. The dependence of time span on task hints on a modulation of implicit processing by task demands and questions the independence of implicit processing from resource allocation or effort (Hasher & Zacks, 1979). The similarity of initial processing in the explicit and implicit mode might speak for a quantitative instead of a qualitative difference between these processes (Mitroff et al., 2002). Both processes might initially share characteristics that are reflected in the N4. The N4 is said to reflect memory processes. These memory processes might only be maintained by explicit processing over a certain amount of time and decay in implicit processing depending on task demands that interfere with the maintenance of representations. This interference between the difficulty of the task and activated representations from memory systems might be reduced by the exogenous cue. The facilitation of representations by the exogenous cue seems to be able to elevate the time span in which implicit processing is sufficient for task performance. It could be argued that implicit processing, as the more parsimonious processing mode, operates at the beginning of task performance. With rising task demands this form of processing might not suffice to solve the task and explicit processing is initiated. Thus, depending on the difficulty of the task explicit processing is initiated at an earlier or later point in time.

The attentional detection mechanism

The ERP components revealed another interesting effect; an attentional detection mechanism targeted on change detection. In the last three experiments different ERP components (namely the P1, N1, N2pc and P3) show a modulation by changes independent of the experimental variations. All these ERP components are linked to attentional processes.

Thus it seems that throughout the different information processing stages (exogenous as well as endogenous components are affected) an attentional detection mechanism is searching for change transients. Nevertheless it is clear that this mechanism is not sufficient for change detection. The experimental variations clearly enhanced change detection. If this mechanism was sufficient for change detection it should vary with the experimental factors with increased activation for increased detection. This however is clearly not the case. It might be that the proposed attentional detection mechanism accumulates evidence for a change transient that does need to reach a threshold to be sufficient for change detection. Several studies on change detection showed modulation of the ERP components found to be also evoked by changes independent of the experimental variations (Block, 2001; Busch, Dürschmid, et al., 2010; Eimer & Mazza, 2005; Fernandez-Duque et al., 2003; Koivisto & Revonsuo, 2003; Schankin & Wascher, 2007, 2008). The authors of these studies conclude that the early components are reflecting attention allocation as a prerequisite for change detection (Busch, Dürschmid, et al., 2010; Eimer & Mazza, 2005; Fernandez-Duque et al., 2003; Schankin & Wascher, 2007, 2008) and possibly visual awareness (Block, 2001; Koivisto & Revonsuo, 2003). In the study by Niedeggen et al. (2001) a P3 modulation was found prior to change detection. Thus it might be that the attentional detection mechanism prepares evidence for a change from early processing stages on and with reaching of the threshold triggers change detection. The P3 however is also consistently found to be elicited by detected changes through its supposed relation to consciousness (Koivisto et al., 2009; Koivisto & Revonsuo, 2003) and decision processes (Eimer & Mazza, 2005). Thus especially the consistent activation of the P3 by the change itself might be indicative for the proposed accumulation of evidence for a change. Nevertheless additional studies are inevitable to research this proposed mechanism.

Semantic, knowledge and learning related stimuli

The experiments reported here were also able to show the relevance of semantic information processing for visual search. As reviewed in the introduction, semantic, knowledge or learning related stimuli are not as widely researched in the change blindness literature as would be expected by their relevance shown in other research fields like natural categorisation (Fabre-Thorpe et al., 2001; Schyns & Oliva, 1999), schemas and scripts (Abbott et al., 1985; Alba & Hasher, 1983; Brewer & Nakamura, 1984), expertise (Bilalic et al., 2010; Takahashi & Watanabe, 2008; Werner & Thies, 2000), implicit sequence learning (Baldwin & Kutas, 1997; Frensch et al., 1998; Goschke & Bolte, 2007) as well as other aspects of visual search (Henderson, 2003). The experiments in this dissertation used semantic information and formed semantic categories with single letters or line drawings to provide a controlled environment in which certain aspects of semantic information processing can be researched without interference from other aspects (for example the activation of additional schemata, categories, etc.). Thus a reduced visual display (as compared for example to real world photographs) was chosen to ensure effective operationalization of the interested semantic object features.

From the presented experiments it is clear that lexical semantic stimuli, semantic deviants as well as the context or semantic category of a scene are able to activate memory traces, which in turn allocate attention in the visual scene thus forming stable representations of scene objects in visual memory. The fact that the semantic information processing is exogenous (able to capture attention without any instruction or explicit highlighting of the stimuli) adds to the assumption that semantic information processing is a general mechanism in visual search (Abbott et al., 1985; Baldwin & Kutas, 1997; Ballard et al., 1995; Bilalic et al., 2008, 2009; Brewer & Nakamura, 1984; Chun & Jiang, 1999; Fabre-Thorpe et al., 2001; Frensch et al., 1998; Goschke & Bolte, 2007; Henderson, 2003; Hollingworth & Henderson, 2000; Kelley et al., 2003; Rensink et al., 1997; Schankin & Wascher, 2008; Schyns & Oliva, 1999; Scott et al., 2008; Werner & Thies, 2000).

Outlook and practical implications

As stated at the beginning of this dissertation, obtaining information from visual search is crucial for our life and many occupational groups. Thus the research on the limitations in visual search as expressed in the difficulty to detect changes between eye blinks, saccades or other visual/attentional interruptions is important. Although there are signs for an attentional mechanism to detect changes, this mechanism is not sufficient for the conscious detection but benefits from cues. The results can be used to design assistance or warning systems for cars/planes or people who have to monitor air traffic or nuclear facilities, etc. The results of the present experiments show that these assistance or warning systems should use semantic/knowledge related stimuli and categorisation to enhance perceptual cues. Thus it might prevent accidents if assistance systems in cars did not only emit a tone but say “red” if the traffic light changed. Furthermore deviants are especially efficient in directing attention and form stable representations. This could be used in advertisement to focus visual attention and commit the advertised product to memory.

Nevertheless, to further explore the attentional detection mechanism additional research is necessary that focusses on the characteristics and limitations of this mechanism. Additionally, the results of the fifth experiment are unclear and thus a longer version of the experiment is necessary to detect if semantic contextual cueing in the proposed form is possible.

Conclusion

To summarize the results of the presented experiments; exogenous (especially semantic) cues are explicitly and implicitly processed and influence the allocation of attention. They also modulate the stability of memory traces and possibly even the level of consciousness necessary for task performance. It is furthermore proposed that an attentional detection mechanism sensitive to changes is working in visual search to process evidence for a change in the visual display.

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Appendix A

Table 1

Categories formed by the line drawings

category	number of included objects
animals	42
household appliances	18
food	18
tableware	12
furniture	12
clothing	12
toys	12
instruments	7
body parts	7
means of transportation	7

Zusammenfassung

Change Blindness (Veränderungsblindheit) ist die relative Unfähigkeit Wechsel zwischen zwei visuellen Szenen zu entdecken, wenn die Transiente des Wechselsignals verdeckt ist (Simons, 2000). Zur Erkennung von Veränderungen zwischen visuellen Szenen ist visuelle Aufmerksamkeit notwendig, um stabile Repräsentationen im visuellen Gedächtnis zu formen, welche daraufhin verglichen werden können. Die vorliegende Dissertation ist konzipiert um den Einfluss von (hauptsächlich semantischen) Hinweisreizen auf visuelle Aufmerksamkeit und Gedächtnis im Change Blindness Paradigma mit behaviouralen und elektrophysiologischen Daten zu untersuchen. Die fünf Experimente zeigten, dass Hinweisreize, welche die Aufmerksamkeit exogen auf sich ziehen, Change Blindness und die Speicherung stabiler Repräsentationen der Szene vor und nach dem Wechsel beeinflussen. Dies passiert sowohl explizit als auch implizit für semantische und perzeptuelle Hinweisreize. Beide Formen interagieren in ihrem Einfluss auf Change Blindness und visuelle Repräsentationen abhängig von der Möglichkeit die visuelle Szene semantisch zu kategorisieren. Diese Bandbreite and möglichen exogenen Hinweisreizen scheint zu zeigen, dass das menschliche System exogene (semantische) Hinweisreize nutzt um die visuelle Suche zu steuern. Des Weiteren konnten Anzeichen für einen automatischen Mechanismus der Aufmerksamkeitssteuerung gefunden werden, welcher der Änderungsdetektion zugrunde liegt. Darüber hinaus stellen die vorliegenden Ergebnisse Theorien in Frage, welche die Change Blindness mit fehlenden visuellen Repräsentationen der Szenen in Verbindung bringen (für Übersichtsarbeiten zu diesen Theorien, siehe Rensink, 2000; Simons & Rensink, 2005).

Eigenständigkeitserklärung

Ich erkläre hiermit, dass ich die vorliegende Doktorarbeit selbstständig ohne fremde Hilfe und nur unter Verwendung der angegebenen Hilfsmittel verfasst habe. Alle sinngemäß oder wörtlich übernommenen Textstellen aus der Literatur bzw. dem Internet habe ich als solche kenntlich gemacht.

Unterschrift

Berlin, 19.02.2015

Datum, Ort