Dimensions of Change Detection within the Phenomenon of Change Blindness

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Introduction

The phenomenon of change blindness (CB) has recently been investigated from a number of perspectives. Basically it entails the limited ability to perceive gross changes in one's visual environment. In a recent experiment, Simons and Levin (1998) showed that persons do not notice when a stranger asking them for directions is switched with another person when the switch is concealed briefly by two persons walking between them carrying a door. CB specifically pertains to limited ability to perceive disparity in scenes, changes between elements ('second-order information') and personal visual impressions (Rensink 2000:2). The rider is that the changes must occur during a flicker, saccade, blink, similar interruption or an eye movement (Simons & Levin 1997; Rensink 2000). One popular way to investigate change blindness is by means of the so-called flicker technique (see Simons 2000). This entails showing persons a series of slides of real-world scenes. A particular aspect of the scene is then changed. The original and the changed slide are shown consecutively with a brief blank slide inserted between them. The interposition of the grey slide creates a flickering display. It was hypothesised that this brief interruption in the visual sequence makes it

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difficult to perceive the changes in the scenes as it disturbs our ability to pinpoint specific changes in the scenes by interposing a series of transient movement changes in the flicker cycle. A number of interesting conclusions were made on grounds of this difficulty to perceive the change in elements of a scene. Firstly, that the brain does not build up or internalise a reasonably full and rich visual representation of the environment. Secondly, CB indicates that this representation is unstable and very sketchy and that one possibly relies on the external environment as a form of a memory extension.

Explanation of CB

In an overview of the literature, Simons (2000) provided five explanations for the occurrence of the CB phenomenon. The causes most often cited are overwriting, first impressions, no storage, no comparison and feature combination. Overwriting or masking pertains to the processes of overwriting the initial image by interposing either the blank slide or the subsequent image. The overwriting effect results in the initial representation being replaced and only the abstract representation remaining. Change can be detected only by attending to certain objects although the attended objects may be abstractly rather than visually represented. The second explanation states that the function of a visual representation is to aid in our search to find a meaningful whole or interpretation of a scene and as soon as this is reached no further processing takes place. Thus the impression of an initial scene is sufficient to gain an understanding of the scene. The changed slide does not necessitate further processing since it seems similar and change is therefore difficult to detect.

The memory extension explanation entails that nothing is stored in any case and the world acts as an extended memory. If nothing is stored then change detection cannot take place. This stronger explanation is supplemented by a weaker claim that some information is stored over successive displays enabling action to take place within a visually changing world. Rensink (2000), for instance, proposed a 'coherence theory' of change detection. Based on the assumption that an environment is visually too rich for veridical and detailed representations to be constructed, it is postulated that *focused attention is needed to see change* (Rensink 2000:19). The coherence theory of attention states that focused attention is responsible for the appearance of temporal and spatial coherence of objects being attended to. A change in an object can only be perceived if it is being attended to at the moment of change.

A person's ability to represent incongruent information or hold disparate beliefs about a particular object or person shows that no comparison is usually made between mental representations until inconsistencies are pointed out. According to Simons (2000) the same might be possible with visual representations. Thus all information is stored but nothing is compared across changes in scenes. However, the hypothesis was that the information was consciously available to a person when prompted, cued or pointed out.

Finally, it may well be that features of both scenes are combined or integrated making it very difficult for persons to distinguish between the two scenes (Simons 2000). Information presented in the form of the original and modified slides are integrated across flickers and this integration is a function of visual short-term memory. One of the requirements of storage performance in this domain is attentive and vigilant processing of scenic elements. This process mediates the encoding of perceived objects. In a flicker experiment only parts of the scene are attended to and attention is not focused on the transient elements and persons have difficulty subtracting one image from another (Irwin 1991).

From the above it appears that attention may play a particular role in change detection. It also seems that persons are not totally blind to changes but that given certain conditions detection of change is possible. This study investigated the role of attention and response latency as mediating variables influencing change detection within the phenomenon of change blindness.

The Role of Attention

Rensink, O'Regan and James (1997) proposed that change in the flicker technique could be perceived if the item that changes falls within the scope of focused attention (see also Rensink 2000). In terms of the information processing taking place, the items within focal attention enters a relatively stable store which, if change takes place, enables one to perceive change by means of comparison with the stored image or item. Unattended items, according to Rensink *et al.* (1997) are overwritten.

Attention is of course not a one-dimensional construct, and in order to determine whether attention does play a role in the perception of change, it is necessary to identify the relevant aspects of attention. In their overview of different classifications of attention, Schweizer, Zimmerman and Koch (2000:273) remarked that '... consistency can only be expected for results that are based on the same class, dimension, and sub-process of attention'. Therefore, it is necessary to clearly define the construct attention.

Three basic processes or systems are usually identified, corresponding roughly to stages of processing, namely orientation, detection and sustaining attention (Ochsner & Kosslyn 1999). Within these basic categories, finer divisions may be made or additional processes can be added. Moore & Egeth (1998) identified feature-based attention which is attention focused on a particular feature of an object (such as the red of a shirt). Schweizer (2001) characterised the processes preceding focal attention as preattentive (bottom-up processing) (see LaBerge 1999). These involve processes that encode 'basic properties' of sensory input and prepare sensory input for focal attention. This process allows for the parallel encoding of the basic elements of a scene such as colour (Treisman & Gormican 1988). Changes in the basic elements may be noticed but changes in associated elements are not easily observed. The attentive processes that follow preattentive attention allows for the serial selection of isolated features of an object (top-down processing) (Kandell, Schwartz & Jesell 2000). However, a finer distinction between sub-processes includes attentional orientation, selective, divided and sustained attention (Coull 1998). Attentional orientation is the propensity towards the salient detail of stimuli, selective attention is the focus on one aspect and not another in the perceptual field while divided attention is the ability to focus on more than one stimulus (cf. Schweizer *et al.* 2000). Sustained attention is the ability to maintain concentration over a period of time. A helpful distinction, which Schweizer *et al.* (2000) alluded to, is that of Sturm and Zimmermann (2000) who distinguished between a selective and an intensity dimension in attention. Selectivity refers to sub-processes of attention such as focal or selective attention and intensity to processes such as alertness and vigilance.

A number of attentional and perceptual processes seem to be implicated when one considers the phenomenon of CB. When an image is screened a person needs to scan the image in order to encode the scene to some extent. In order to perceive a change attention needs to be sustained. However, the demand is relatively high in contrast to sustained attention with a low level of demand from a concentration task extended over a period of time. In a situation such as the latter habituation sets in and mistakes are easy to make (cf. Manly, Robertson, Galloway & Hawkins 1999). In the flicker technique the disruptive nature of the flicker increases the demand to such an extent that habituation is difficult. The flicker technique places high demands on sustained attention but also requires sustained focal attention—one can scarcely imagine divided attention playing a role since the disruptive nature of the flicker masks changes in the image. However, this could be precisely what happens: divided attention which has the function of focusing attention by changes or movement in stimuli could be disrupted by the masking effect of the flicker hindering the full coding of changes. This prevents the visual experience of change from reaching consciousness. If this is the case, eye movement studies could indicate whether the area of change in the image draws the eyes more frequently than other areas in the image. This could indicate that pre-conscious processing is taking place and that divided attention is operative to some extent.

However, the task in the flicker technique seems to require focal attention since it is only by looking at the precise point of change that it is noticed (cf. Rensink *et al.* 1997). It seems as if selective attention as a sub-process is operative and disrupted since one needs to discriminate between a transient caused by the flicker and a change in stimulus (the change on the image).

Taking sustained attention and selective attention to be the sub-processes involved in change detection, it was hypothesised that those persons with the ability to a) maintain accurate concentration over a period of time and b) discriminate between the details of an image will be able to perceive change and do so more expeditiously.

Response Time and Detection of Change

The detection of change in the experiments is dependent on the length of time taken to initiate a response. Research on change blindness has concentrated on the behavioural aspect, namely reaction time (Güzuldere 2000). In these studies the researchers have included a measure of the response bias of subjects in order to correlate time to response and accuracy of response. A reaction test was included in this design to investigate whether individuals with faster reaction times on the choice reaction test would have shorter response latencies in the change blindness test. Response time was operationalised into two steps that reflected underlying information processing stages. Information processing is associated with a person's overall cognitive ability and the complexity of the information to be processed (e.g. single feature or conjunctional feature). The stimulus identification stage (Adam 2000) corresponds to the finger lift in the reaction test recorded as decision time (see discussion below). The first stage together with the motor programming stage corresponds to the key press in the reaction time test (recorded as reaction time) These processes interact in a dynamic manner. For this study it was translated into a composite reaction time score. It is hypothesised that image changes as reflected in the change blindness experiment are considered to be either single feature differences or conjunctional feature differences. Limited processing is required to detect changes (and hence faster reaction times) for single feature differences because of the parallel processing required for executing this task. In contrast, the detection of conjunctional differences requires sequential processing to differentiate between the objects and the distractors (Treisman 1986). The processing that underlies this task is complex and includes perceptual detection, cognitive decisions and visuomotor responses. It was hypothesised that other processes are involved in the ability to detect change quickly. In this study these were operationalised as a composite of perceptual, cognitive and visuomotor abilities.

Method

A sample size of 120 was aimed for in order to allow for a more complex design. However, the realised sample consisted of 94 first year psychology students recruited from the University of Pretoria. Students who attended the psychology classes were introduced to the research and were asked to volunteer. They were required to fill out a short screening questionnaire and a consent form. The screening questionnaire included items on medical conditions especially epilepsy. Persons not complying with basic criteria were excluded from the sampling list. Although it was shown that the phenomenon of change blindness was reasonably resistant to transference, it was felt that transference should be minimised by scheduling testing times as close as possible. The tests were available on IBM-compatible computers in a selected computer laboratory. Each participant had access to a computer and on average a testing session comprised of 10 participants with a tester appointed to each participant. Groups were also asked not to discuss the experiments and tests with their friends.

Three tests were used, namely a reaction response test, an attention test and a flicker test. All three tests were programmed in house.

(a) The reaction test consisted of a series of stimuli shown on screen. Two keys were allocated as a rest and a response button. The testee kept a finger on the rest key until the correct response was shown. The response key was then pressed with the same finger as quickly as possible. The test followed the classical choice reaction test paradigm. Three circles were shown on screen, namely yellow, red and blue. The intensity was low so that the colours were dark or subdued. During the test these circles brightened in different combinations and a response had to be executed only for a yellow bright and red bright circle combination. The positions of the coloured circles were always the same. A total of 12 stimuli were shown. If a person lifted his/her finger for an incorrect stimulus then it was recorded as a decision error. If the person pressed the response key as well, then it was also recorded as a reaction error. Times for correct responses were recorded as follows: the time that elapsed from the moment of observation to a finger lift was recorded as decision time in milliseconds. The time in milliseconds since the stimulus was shown until the response key was pressed was recorded as reaction time.

(b) The attention test was developed to incorporate the requirements for the sub-processes of selective and focal attention: (i) it should allow for low to medium demand on selective attention, i.e. tasks ought to hold attention but not be too complex thus involving higher cognitive processes and (ii) must not be too simple and induce a habituation effect. The stimuli and task were developed to comply with these requirements. Two examples of attention assessment tasks involve (i) pressing a key in response to stimuli until a stimulus not requiring a key-press is shown (Manly *et al.* 1999) and (ii) pressing two different keys, each corresponding to different type of stimuli (Schuhfried 1989). Both actually require similar tasks. Two types of stimuli require different responses. However, (i) above facilitates habituation due to the infrequency of no-response targets, while (ii) requires a reasonable level of vigilance or alertness due to a visual comparison task and reasonably frequent occurring alternative response targets.

The attention test consisted of showing a number of figures in squares on screen with one figure below them, which changed as soon as a key was pressed. The requirement was to compare the single figure with the five figures and indicate whether it was similar or different to the five figures. The five figures stayed the same throughout the test. Two keys on the keyboard were allocated to indicate whether a figure was similar or different. The sequence of the changing figures was preset and was repeated as long as the test ran. Since, the sequence was long and randomised it was very difficult to memorise. The test ran for 5 minutes and the testee determined his/her own pace and level of accuracy. A practise session was given and could be repeated until the testee felt comfortable with the test. Reactions were recorded as arrays of correct and incorrect responses in 30-second segments. From this data the total number of responses, and the number of correct and incorrect responses were calculated. The total number of responses indicated work speed, while the ratio incorrect over correct responses yielded an indication of concentration quality.

The hypothesis for the attention test was as follows: persons that are able to respond correctly over a period of time would be faster at observing changes in the flicker test.

(c) The flicker test consisted of the same slides used by Rensink *et al.*

(1997)[2]. Slides consisted of photographs of real-world scenes ranging from nature to urban images. An original and a changed scene was displayed for 240 ms with a grey blank scene disrupting this cycle for 80 ms. This followed the Rensink *et al.* (1997) sequence of A, A, A', A' where A stands for the unchanged image and A' for the changed one. The whole cycle was repeated until a person pressed a button to stop the display. A testee was then asked to report the observed change where after the tester typed in either c for correct or i for incorrect. The image was displayed on a computer monitor and the slide size was 27 degrees wide and 18 degrees high. The slides reflected both marginal interest changes (MI) and central interest changes (CI). In Rensink's investigation the distinction between central and marginal interests was drawn on the basis of independent classification by observers and consisted mainly of whether the change formed part of the central theme or the main gist of the picture or not. It was hypothesised that central interest changes would be noticed quicker than marginal interests. The types of change that subjects could encounter between the original and modified image included object colour, object omission/disappearance and object location changes. The time that elapsed between the observation of the scenes and the reported change was recorded in milliseconds as a latent response. The testee was exposed to 6 practice slides and could repeat the practice session if needed. The 6 practice slides were included again in the test. To counter a sequence effect in the flicker test the order of the images was randomised for each testee. The flicker test was the last in the sequence of three tests.

Results

(a) The first comparison between type of change and interest yielded no difference (see Figure 1). Rensink *et al.* (1997) found significant differences between marginal and central interest, which the current experiment could not confirm. Paired sample t-test yielded no significant differences between MI and CI for each change type. However, the order of reaction time in terms of number of cycles was reasonably similar to the Rensink experiment. They (1997:370) found that MI's took an average of 17.1 (10.9 s)

[2] The original images with helpful suggestions were kindly provided by Ronald Rensink.

alternations while the current experiment found and average of 14.37 (9.2 s) alternations. For CI's they found 7.3 (4.7 s) alternations while this experiment found 13.442 (8.6 s).

(b) To determine the effect of attention accuracy on the perception of changes, a comparison was made between three categories of attention accuracy (poor, average and good). To repeat the hypothesis stated above: one would expect persons that were able to respond correctly to the required stimuli in the attention task over a period of time to notice changes more quickly in the flicker test. The sample was divided into three equal groups based on the proportion of inaccurate responses over total responses.

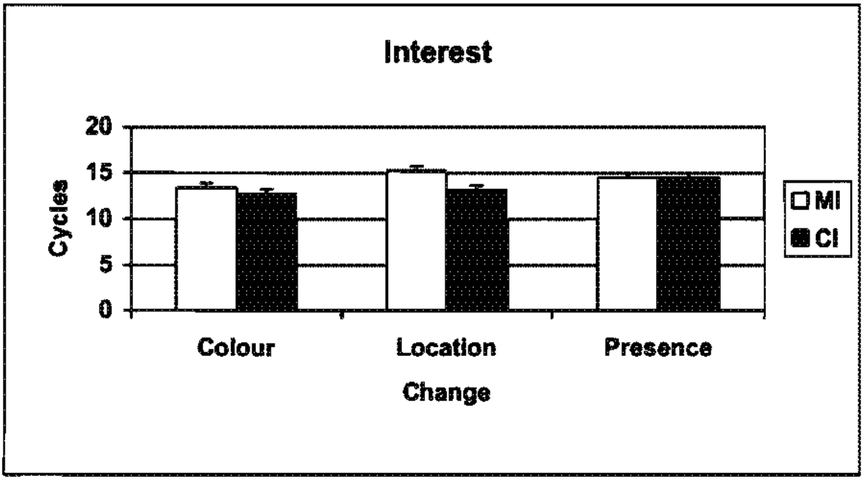

Figure 1: Interest

Figure 2 shows that a slight decreasing trend for reaction time was found for the poor concentration group. The presence/absence change was affected most in comparison to the other categories of concentration quality. A two-way within subjects ANOVA for change type and concentration yielded no significant main or interaction effects. A one-way ANOVA for presence yielded significant differences between the three groups, $F(2,89) = 4.13$, $p <$

0.05. Scheffe's post-hoc test indicated a significant difference between the poor and the average group (p < 0.05).

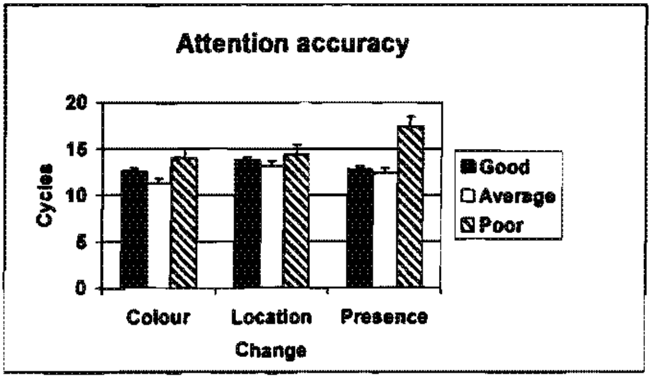

Figure 2: Attention Accuracy

(c) The reaction response test yielded reaction time scores, which provided an indication of speed of processing capacity. The sample's reaction time was also divided into quick, average and slow reaction speeds. The data was analysed with a similar two-way within subjects ANOVA for change type and reaction time. A main effect for reaction time was found, $F(1,90) = 4.625$, $p < 0.05$.

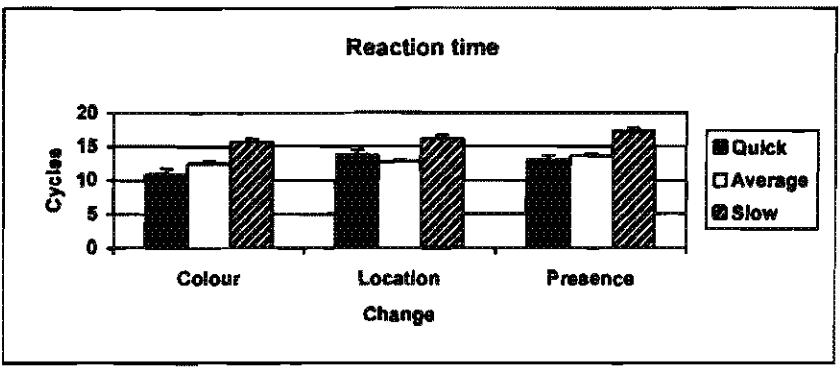

Figure 3: Reaction Time

again indicated the slow group as differing from the other levels especially the fast group in the colour and presence change types. A separate one-way ANOVA on the change types showed that significant differences were restricted to the colour change, $F(2,90) = 5.35$, $p < 0.01$. Scheffe's post hoc test indicated a significant difference between the quick and slow groups, $p < 0.01$.

Discussion

This study was very conservative in its approach to CB since it was planned as a basic replication of the Rensink *et al.* (1997) experiment. It went one step further by exploring the relationship between response latency and CB and attention and CB. A number of studies including Rensink *et al.* (1997), postulated attention as the prerequisite for changes in scenes to be detected across transients.

The present experiment indicated similar response latencies for change detection as Rensink *et al.* (1997) found. The main finding of the current experiment indicated no significant difference between marginal and central interests. This finding contradicted the results of Rensink *et al.* (1997). Given the consistent difference by interest found in other studies such as Rensink, O'Regan and Clark (2000) and O'Regan, Deubel, Clark and Rensink (2000), it was surprising not to observe this difference in the current experiment.

A number of aspects needed to be ruled out before one can speak of construct failure. With construct failure we meant that finding a difference between interest types could be an artefact of particular circumstances rather than the construct itself. Finding a difference or not could be caused by the test itself, the test conditions and the sample. Of course the construct validity could be low which means that the way interest is defined and classified is inconsistent. Attempts at refining the interest construct were made, for instance, by Hollingworth and Henderson (2000), who distinguished between the visual and semantic aspects of an interest-type change. For the current experiment one may rule out the technical and test condition aspects except if for some reason issues such as screen luminance or lab conditions differed from the original experiment and influenced the results. Since the internal conditions with respect to the current experiment were kept standard, one would expect the distinction between interests to show up. We could identify two possible culprits, namely viewing the slides from a fixed distance and the nature of the sample. The speed with which changes on screen can be seen could relate to the viewing distance, which was not strictly controlled in the current experiment. An approximate arms-length viewing distance was maintained. On the other hand given the large sample size, one would expect artificial differences like these to average out and still yield an indication of a difference between the interest-types. The sample size in this case is a strong argument for construct validity and possible sample characteristics. We are only now beginning to suspect that factors over and above attention or basic information processing mechanisms are responsible for the speed of change detection. If semantic content of a change mediates its detection speed, aspects such as perceptual style and stimulus dependency/independency could just as well play a role in change detection speed.

The results of the experiment do not deny the phenomenon of change blindness and the corresponding mechanisms responsible for it (which researchers are trying to figure out), but it could point out that a more/less principle exists when investigating basic perceptual and cognitive mechanisms. We all breathe air, but some of us absorb oxygen better than others. Thus, change blindness is caused for instance by the disruption of representations between transients (which is true for most persons), but the speed of change detection is a function of any number of variables of which persons may have more or less of. In this particular sample consisting of volunteers, interest, stimulus dependency, scanning speed or even attentional capabilities may have been high (the highly attentive introvert with slow but accurate perceptions would probably not have volunteered), thus biasing the results—they could have just been good at detecting changes in any case! These hypotheses can be investigated in a second round of experiments and would be very informative in their outcome with regard to the CB-investigations.

Since one of the more prominent explanations for the phenomenon of change blindness was that it related to attention, the current experiment included the attention test, which focussed on aspects of sustained and focal/selective attention. The sustained aspect was built into the test due to the requirement of remaining vigilant over a period of time (in this case five minutes). The sub-process involved was assumed to be an aspect of focal attention. Thus a person was required to compare a target with a number of static figures, decide whether it was similar and press a corresponding key. We were interested in a person's ability to execute the task correctly, which was indicated by a low percentage of incorrect answers. The results for the attention test showed no significant main effects for change type and attention accuracy or their interaction. However, doing an ANOVA for each change type separately yielded a significant difference between low attention accuracy and average accuracy for the presence/absence change. The low accuracy persons were markedly slower in detecting changes. Although the results indicated a trend towards inaccurate performers detecting changes slower than the other categories of attention quality, the results were inconclusive and it was difficult to relate attention and change detection in this experiment.

One may indeed ask whether attention is playing a necessary *and* sufficient role in detecting change or whether the role is merely necessary since other factors such as the meaning of the picture moderates change detection (see Pani 2000; Werner & Thies 2000). This was the question Hollingworth and Henderson (2000) probed. They made a distinction between visual and semantic informativeness of changes within a scene. Visual informativeness included aspects such as the size, position and complexity of the changed object, while semantic informativeness refers to whether the change made sense or not. A semantically incongruent object will be more informative than a changed object that fits within the scene. Their study found amongst others that change detection was quicker for semantically informative changes within a scene than for semantically uninformative changes while visual informativeness was kept constant. This finding of course pertains to the question of how the construct of interest is defined, but Hollingworth and Henderson (2000) also tested whether semantic incongruent objects in any case caused more and longer eye fixations in the region of change. Overt attention would explain why a particular change (in this case an incongruent one) was detected faster.

However, they found that by limiting the ability to fixate on targets, the semantic informative changes were still detected faster. Thus, according to their findings cognitive rather than attentional factors seem to be involved in the speed of change detection.

The current study tentatively indicated that attentional factors may not play such a major role in change detection—it is a necessary but not a sufficient condition for detection to take place. One scarcely can imagine *not* looking or attending to aspects of a scene and then seeing it. The fact that persons with low accuracy took longer to perceive changes in the presence/absence of objects fits in with this explanation. The attention test probably tapped the same ability required to detect the presence/absence of objects—the target figure in the attention test had an additional segment added or subtracted. The slower detection times of the low accuracy performers probably indicated that attention was a necessary condition to detect change. The fact that no response latency differentiation was found between average and better attention performers could point to attention not being a sufficient condition. A number of questions relating to attentional factors can be explored. For instance, will an attention test tapping colour or location changes yield similar results thus showing attention to be feature sensitive? If this is the case, then one can probably determine the extent to which attention does contribute to change detection. The ability to make finer distinctions opens up further investigative possibilities by separating attentional, cognitive and other resources contributing to change detection.

The reaction test showed that persons do differ in terms of reactive capabilities. Reactive capabilities in the present study alluded to perceptual, cognitive and visuomotor abilities. Although the test was a choice reaction time task, these abilities, taken together, played a prominent role in the execution of tasks. The hypothesis was that additional processes to attention might facilitate the speed of change detection since reactive capabilities differ amongst persons. To some extent this hypothesis may be accepted due to the overall difference in reactive capabilities. However, the specific relationship between reaction time on the reaction test and speed of change detection on the colour feature of the flicker test may support the conclusion outlined above. The reaction test was based on colour stimuli and as the case was with the attention test, the same feature was identified by the flicker test. To reiterate, are tests of attention and reaction feature sensitive? If so, is it due to our ability to make finer visual detections and/or is some element of priming occurring where traces of neural activity exists and are transferred to the types of detection in the flicker test?

Conclusion and Recommendation

The study replicated the Rensink *et al.* (1997) experiment but also increased the sample size and investigated the role of attention accuracy and response capability in mediating change detection. One of the major findings of the experiment related to the possibility that both attention and reactive capability could be feature specific. In other words, the detection of colour, location and presence/absence changes might involve specific processes in the brain. When making attention responsible for mediating change detection, it is probably an overestimation of what is actually responsible for change blindness. It is an overestimation in the sense that very specific attentional and cognitive processes are involved in detecting very specific changes. Attending to colour is probably qualitatively different to attending to location. This has an implication of how we design tests for attention and reactive capabilities. We may gloss over very real differences on a micro or featural level by making for instance, focal attention responsible for detecting all kinds of changes. Current research supports this line of thought by finding evidence for distinct brain regions corresponding to specific sub-processes of visual attention (Heuttel, Güzeldere & McCarthy 2001).

We may speak of an overestimation of attention as responsible for change detection in a second sense as well. Attention and other processes may be responsible for change detection in a minimal sense. Without it you can never see change, but up to a certain point increased capability does not increase the ability to detect change. Other processes may then start mediating change detection such as the semantic content of changes or the gist of a scene.

Lastly, the presents study's finding with regard to interest opens up alternative avenues for further research. The distinction between interest types needs to be reconceptualised using larger samples and more specific criteria to make allowance for issues such as semantic versus visual informativeness. Its inclusion in studies of change detection is necessary because of the psychological and higher level factors that underlie persons' interest, which in turn mediates detection of change within the CB phenomenon.

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