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The quality of perception without attention

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Summary and discussion

CHAPTER 8

Although we experience a rich and detailed world every time we look around, we do not have the capacity to report about all that we experienced if the scene is taken away. Our limited attentional capabilities restrict us to only report about the few items that we happened to attend to. Does this imply that we are never conscious of more than a few items at once? Or should our definition of consciousness include the unattended part of our perceptual experience? The discussion about whether we consider a certain process as conscious or unconscious depends for an important part on definition. In this thesis, I provide data to inform this discussion. I first determined that we can study unattended stimuli behaviorally by examining different stages in visual short-term memory. I then examined whether certain characteristics that are associated with consciousness – such as information integration that support perceptual inference (see Fig. 1.1) and explicit information processing – are present for these different stages of memory. Last, I looked at the neural signature of unattended stimuli to investigate whether the same type of perceptual processing occurs as for attended stimuli. In sum, I found that unattended processes display many of the characteristics that we normally associate with attended processing. Below, I will first summarize and interpret the main findings of this thesis, and then discuss what this might imply for the study of consciousness.

Fragile Memory can be dissociated from Working Memory

To study the richness of unattended perception behaviorally, we compared the qualities of visual sensory memory to those of visual working memory (WM). WM represents the capacity to maintain information over a brief period of time (seconds to minutes), and is known to depend on attentional processes (Awh et al., 2006; Chun, 2011; Chun & Turk-Browne, 2007; Gazzaley & Nobre, 2012). Sensory memory, on the other hand, is a high-capacity, but quickly decaying memory storage, and it has been proposed to represent the rich visual world we experience (Sperling, 1960). This makes sensory memory a possible candidate for unattended conscious processing. Sensory memory has been shown to have two stages: the first, termed Iconic Memory (IM) only lasts for a few 100 ms, and is partly dependent on retinal afterimages. The second stage, termed Fragile Memory (FM), can last for up to a few seconds and has a cortical basis (Sligte et al., 2008). Therefore, especially FM makes a likely candidate for conscious, but unattended processing. Whereas IM might reflect lingering retinal activity, FM could represent a stage in which perceptual qualities have arisen through integrative neural processing, but these are not yet reported about due to limited attentional capabilities. That FM is indeed different from IM has been agreed upon (Sligte et al., 2008), however, whether FM represents a different, unattended, stage of memory compared to WM remains unclear. Chapters 2 and 3 describe two experiments that reveal a dissociation between FM and WM based on their attentional and underlying brain mechanisms.

In Chapter 2, I tested the hypothesis that FM is a stage in Visual Short-Term Memory (VSTM) that, in contrast to WM, is formed independent of focused attention. First, we showed that when subjects were presented with multiple memory displays, and didn't know which display would be the last and thus the one to remember, their WM capacity suffered considerably, while FM stayed relatively intact. Second, when subject were engaged in an attentionally demanding task while the memory display was shown, WM capacity decreased much more than FM capacity. Third, when the memory display was incorporated as the second target in an attentional blink paradigm, WM capacity showed the largest decrease if the display was presented close in time to the first target, indicating an effect of the attentional blink. FM capacity, on the other hand, suffered to a lesser extent, and regardless of whether the display was presented close in time to the first target or not. These three experiments demonstrate that during encoding of a memory display, focused attention is an important factor in the formation of WM representations, while it is less so for FM representations.

In a recent study, Sligte et al. (2011) applied TMS over the Dorsolateral Prefrontal Cortex (DLPFC) after presentation of the memory display, but before presentation of the cue. They showed that WM capacity dropped when TMS was applied, while FM capacity remained intact. Thus, the DLPFC – a structure that is important in attentional deployment (Pessoa, Kastner, & Ungerleider, 2003; Slagter et al., 2007)– plays a role in forming (or maintaining) WM representations, but not in forming FM representations. Chapter 2 matches with this study: both studies indicate that WM is a form of memory that depends on attentional deployment whereas FM can be encoded and maintained when attention is diverted.

Recently, Persuh, Genzer & Melara (2012) have challenged the argument that attention is not necessary to form sensory memory traces. In their experiment, subjects performed two tasks: 1) a visual search task – presented in the center of the screen - in which they had to locate a deviating stimulus, and 2) a change detection task for which the memory display was presented in the periphery surrounding the search task. They found that sensory memory capacity decreased when subjects performed the two tasks at the same time, from which they drew the conclusion that attention is necessary for the formation of sensory memory traces.

Crucially, however, the authors did not compare sensory memory performance to WM performance. Logically, performing a dual task decreases memory capacity, because the task demands themselves become larger. However, the important question is whether sensory memory decreases less than WM. Only a comparison between sensory memory and WM could reveal whether the formation of sensory memory is less dependent on attention than WM is. In addition, because the visual search task was presented simultaneously with the memory display, perceptual load was heavily manipulated. This might have interfered with the perceptual processing of the memory display instead of with its attentional processing (Lavie, 2005; Yi et al., 2004). This is supported by the fact that when the visual search task was easy (shown by a performance of 99% accuracy), a significant decrease in sensory memory capacity was found as well (a reduction of 12%). This shows that perhaps not attentional, but perceptual load was the key factor that manipulated sensory memory performance here.

Of course, we do not want to claim that all forms of attention are unnecessary for sensory memory traces to be formed. To process the memory display and perform the task well, subjects need to be vigilant and concentrated on the task, which could qualify as a form of global attention. The main point that we want to address, however, is that the formation of sensory memory representations depends less on attentional enhancement and more on visual processing, while the formation of WM representations is manifested by attention that is focused on an object.

That some form of visual concentration or excitability is important for sensory memory was shown in Chapter 3. Here, we correlated FM and WM capacity with oscillatory EEG power. We showed that FM capacity is related to an increase in frontal gamma power before onset of the memory display. This increase in frontal gamma occurred simultaneously with a decrease in peri-occipital alpha power and these modulations were in turn correlated with each other. This suggests that preparation for the memory display through top-down control increased FM capacity, but not WM capacity. In addition, there was a positive correlation with FM capacity for the theta band at central-parietal electrodes after onset of the memory array, together with a slightly negative correlation for WM capacity, showing that better processing of the memory display specifically increased FM capacity. Together, these data show that enhanced visual preparation and enhanced memory display processing were related to a larger FM capacity, but not to a larger WM capacity. This suggests that FM is much more visually based than WM, which further supports a distinction between these stages in Visual Short-Term Memory.

Together, Chapter 2 and 3 show that FM can be dissociated from WM based on its attentional and oscillatory underpinnings: FM is not as dependent on focused attention and relies more on visual processing than WM. This makes FM a possible candidate for unattended visual consciousness. To investigate whether the processes that underlie FM indeed reflect conscious processing, I investigated whether the qualities of FM representations resemble those of WM representations.

The nature of sensory memory

To be able to say that conscious processing can occur outside attention, one must show that unattended processing has the same qualities and characteristics as attended processing. As was shown in Chapter 2, and in many other studies investigating the role of attention in memory, WM is a form of memory requires attention to be formed (Gazzaley, 2011; Vogel et al., 2005), and maintained (Allen et al., 2006; Awh et al., 1998). In addition, since WM contains information we can manipulate and report about, it is thought to reflect conscious, explicit processing (Baars & Franklin, 2003; Lamme, 2006). Therefore, if sensory memory representations have the same characteristics as WM representations, one might conclude that unattended visual processing does not differ from attended visual processing apart from the fact that it is not reported about.

To investigate the perceptual qualities of sensory memory, we used Kanizsa illusions (Kanizsa, 1976) as memory items instead of oriented rectangles (Chapter 4). In the Kanizsa illusion, integration between higher-level and lower-level visual brain areas creates an illusory figure (Knebel & Murray, 2012; Wokke et al., 2013).This illusory figure is defined by illusory contours and an illusory contrast difference between figure and background. The Kanizsa illusion is a prime example of perceptual inference, as it adds a perceptual characteristic to the physical stimulus properties: we do not only know that a figure can be inferred (implying cognitive inference), but we actually perceive the figure as if it were there. This distinction between cognitive and perceptual inference can be compared to for example knowing that a car has moved, because you see it in a different place the second time you look, with actually seeing the movement of the car (Pylyshyn, 1999).

When subjects performed the partial-report change detection task containing Kanizsa illusions, performance was enhanced compared to a control condition in which the same stimulus inducers were present, but now rotated such that no illusion was formed. This increase in performance was evident for both sensory memory (IM and FM) and WM. Importantly, the increase in performance was larger for IM and FM than for WM, which was expected based on their different baseline capacities; in the control condition, IM and FM performance were already larger than WM performance. That the boost in performance was larger for IM and FM when Kanizsa illusions were used showed that this boost was not only driven by a potentially shared working memory component between conditions, but that the Kanizsa illusion could be stored in IM and FM as well.

Given the fact that a retro-cue is necessary to probe report of the Kanizsa figures, one could argue that the retro-cue itself guided attention and therefore, the inducers are bound and the figure was formed only by virtue of the cue. However, if this were the case, then all the inducers in the Kanizsa condition should have been maintained separately in IM and FM before onset of the cue. As in the control condition it is assumed that the inducers were not bound (or very poorly bound), separate maintenance of inducers in FM would imply that the same number of inducers should be remembered in the Kanizsa condition as in the control condition. The fact that performance was lower in the control condition compared to the Kanizsa condition shows that the inducers were already bound before presentation of the retro-cue.

In the second experiment of Chapter 4, we examined whether the extra boost in performance for IM and FM was due to perceptual inference by removing the illusory nature of the Kanizsa figure; we made the inducers isoluminant with respect to their background. This eliminated the illusory contours and illusory contrast difference between figure and background, and thus eliminated the perceptual inference characteristics while leaving the figures' spatial organization and cognitive inference intact. Now, the benefit for the Kanizsa figures was the same for IM, FM and WM. Thus, the extra boost found for the black-and-white Kanizsa figures could be attributed to the perceptual quality of these Kanizsa figures and not merely to their spatial organization, cognitive inference or to attentional selection through the retro-cue. This suggests that perceptual qualities that arise through higher-level integration are present in unattended memory representations.

In Chapter 5, we investigated whether sensory memory performance is based on implicit or explicit processing by comparing metacognition for IM and FM with metacognition for WM. Metacognition scores reveal the degree to which subjects can accurately reflect on the correctness of their decisions (Fleming et al., 2010; Metcalfe & Shimamura, 1994), and thus measures the extent to which the decision is based on explicit processing. We expected that if sensory memory is based on explicit processing to the same extent as WM, metacognition for IM and FM would be equal to metacognition for WM. Moreover, we tested the objective decision criteria for IM and FM versus WM. Decision criteria are known to be negative for unattended and positive for attended items (Rahnev et al., 2011), but at the same time can affect metacognition scores (Barrett et al., in press; Maniscalco & Lau, 2012). Therefore, if the decision criteria would be negative for IM/FM and positive for WM, this would support the claim that IM/FM represent unattended forms of perception while WM represents attended perception.

However, if a difference in decision criteria is found, these differences should be taken into account and the measure for metacognition should be adjusted as well.

In Experiment 1 of Chapter 5, we found that when subjects performed a change detection task with oriented rectangles as memory items, metacognition for IM and WM was equal, and metacognition for FM was slightly higher than metacognition for WM. This suggests that representations in FM are even more explicitly available for decisions than representations in IM and WM. In addition, we found that the objective decision criteria for IM and FM were negative, showing a tendency to respond 'change' more often than 'no-change', while the objective decision criterion for WM was positive, indicating a tendency to respond 'no-change' more often than 'change'. This difference between decision criteria exactly followed the pattern for unattended (negative criterion) versus attended (positive criterion) stimuli found by Rahnev et al. (2011). Therefore, these results support the conclusions drawn from Chapter 2 that FM represents an unattended stage of memory, while WM reflects an attended form of memory. However, since a difference in decision criteria in combination with the high hit and/or false alarm rates observed in this experiment might have influenced metacognition scores (Barrett et al., in press), we performed a second experiment in which we used a change-identification task using oriented arrows. In this task, subjects reported whether the change – that occurred on 100% of the trials – was clockwise or counter-clockwise. With change-identification no difference in decision criteria between conditions is expected, because under the signal detection theory these two stimuli (and thus their thresholds) are interchangeable. Now, metacognition for IM was somewhat lower, but metacognition for FM and WM were equal. This shows that when controlling for confounding factors, FM and WM still depend on the same amount of explicit processing. Thus, unattended representations, at least those that last for more than a few hundred milliseconds (FM), are explicitly processed just as attended representations are.

Together, Chapter 4 en 5 show that unattended representations have the same qualities and depend on explicit processing just as attended representations. This contradicts what other scholars have said about unattended representations (de Gardelle et al., 2009; D. Rahnev et al., 2011). De Gardelle et al. (2009) found that when a letter display is presented briefly just as in the classical Sperling experiment (see Fig. 1.2), a stimulus that deviates slightly from the rest of the display, e.g. a mirrored letter R, is not reported about when probed after performing the sensory memory task (de Gardelle et al., 2009). In other words, when subjects are cued to remember one row of letters, they are not able to report about deviating stimuli in any of the uncued rows. The authors therefore concluded that our introspective feeling of seeing more than we can attend to is illusory. The design used by de Gardelle et al. (2009), however, was not optimal to measure unattended processing. The crux of measuring sensory memory is that it can only be retrieved when a retro-cue guides attention before other intervening stimuli are able to interrupt this process (Sligte et al., 2008; Sperling, 1960). If subjects are asked to report the deviating stimulus after having reported another row, sensory memory traces have decayed, and most likely what is measured are representations that are left in WM (Block, 2011). Therefore, this study does not reveal anything about the nature of sensory memory representations, but rather shows that when stimuli are briefly presented, representations that are stored in WM are easily confounded.

Another recent study has shown that when subjects perform a stimulus detection task for attended and unattended stimulus locations, their decision criterion for the unattended location is negative, meaning that they have a bias towards detecting a stimulus in the unattended location more often, even when it's not there (Rahnev et al., 2011). In addition, subjects also gave higher confidence ratings for unattended locations. Together, this seems to suggest that what we believe to perceive in unattended locations is based on overconfidence in wrong judgments. However, Rahnev et al. (2011) did not look at metacognitive performance, but interpreted data from objective and subjective responses separately. Therefore, although they could conclude that for unattended representations, subjective confidence ratings were higher, they could not draw any conclusions about metacognition for unattended representations.

Although it is clear from Chapter 5 that FM representations are explicitly processed to the same extent as WM representations, metacognition for IM was slightly lower. This suggests that IM is based on implicit processing more than FM and WM. Also, when subjects had to discriminate between orientation changes in arrows, IM capacity did not differ from FM capacity. This finding coincides with the results from Chapter 4. There, we showed that there was an extra benefit for Kanizsa figures versus control figures for IM and FM compared to WM, however, this extra boost was the same for IM and FM. Based on the fact that IM had a higher baseline capacity than FM, one would have expected the boost for IM to be even larger than for FM. Possibly, when stimuli are too complex they are not represented in IM, but only in FM. The mechanism underlying FM might be based on higher-order brain areas such as V4 (Sligte et al., 2009) and perhaps object processing areas like LOC (Sligte et al., 2010), while IM could be confined to a retinal afterimage or perhaps early visual areas like V1. If this would be the case, when more complex information needs to be remembered, higher-order brain areas are necessary to process the objects and thus only FM capacity remains and IM does not outperform FM. Therefore, I propose that while unattended processing might be as rich as attended processing, visual qualities only arise when the information has lingered for more than a few 100 milliseconds and has been processed by higher visual brain areas to create an integrated whole.

Neural measures of the quality of perception

Behaviorally, we have shown that the characteristics of unattended processing resemble those of attended processing. Now, I will discuss what happens at a neural level during unattended processing. The advantage of taking a neural approach is that neural measurements are independent of report: using neural measurements we could investigate the quality of perception that is not only unattended, but also unreported.

In Chapter 6, we investigated the neural fate of unreported stimuli using an Inattentional Blindness paradigm. Here, subjects performed an attentionally demanding letter task while a Kanizsa figure was presented surrounding the letters. Half of the subjects were not able to identify the Kanizsa figure when asked about it afterwards. However, the neural signature of the Kanizsa figure was the same for the group that could not identify the figure as for the group that could identify it. In addition, we could use the neural pattern of the unreported Kanizsa figure to predict presentation of the reported Kanizsa figure, and this prediction outperformed prediction of several control stimuli. This shows that the representation of unreported and reported Kanizsa figures are highly similar, suggesting that the qualities that are unique to the Kanizsa figure arose independently of report.

But can Kanizsa figures be considered hallmarks of conscious processing? It has been shown that the Kanizsa figure is not perceived when its inducers are made invisible by use of continuous flash suppression, suggesting that conscious perception of the inducers is necessary to form the figure (Harris et al., 2011). However, other studies have shown that the Kanizsa figure can be processed unconsciously as well (Lau & Cheung, 2012; Wang et al., 2012). Although these findings seem to contradict each other, it could be that the formation of the Kanizsa figure depends on both conscious and unconscious processing. The initial grouping of the inducers might depend on fast, feedforward activity (Roelfsema, 2006). Then, the details of the figure – the specific illusory shape that is seen – are filled in by feedback mechanisms (Conci et al., 2009; Harris et al., 2011; Wokke et al., 2013). The fact that in Chapter 6 mean activity in V1 and V2 was enhanced for the Kanizsa figure suggests the involvement of feedback mechanisms: the receptive field sizes in V1 and V2 are too small to encapsulate the entire Kanizsa figure used in this experiment. Thus, feedback from higher areas probably modulated activity in lower visual areas, thereby suggesting that processes underlying shape formation had occurred and the figure was fully processed (Harris et al., 2011; Wokke et al., 2013). Although the initial feedforward activity that enables grouping might occur unconsciously (Roelfsema, 2006; Wang et al., 2012), the feedback process that modulates the shape formation is suggested to rely on conscious processing, since disrupting this process prevents the shape of the figure to be reported about (Harris et al., 2011; Wokke et al., 2013). If we agree that the shape formation – and thus the perceptual quality of the figure - is a conscious process, we must conclude that conscious processing occurred for the Kanizsa figures during inattentional blindness.

In Chapter 7, we investigated which brain areas support the effect that object knowledge has on color vision. We showed that both in visual and frontal areas the neural pattern of an ambiguous color lying midway between red and green shifted towards green when presented on typical green objects (like a clover) and towards red when presented on typical red objects (like a tomato). This suggests that we do not only categorize the same color differently depending on our semantic knowledge (Mitterer & De Ruiter, 2008), but also perceive this color differently. Moreover, that neural representations in both higher and lower visual areas were modulated by prior knowledge indicates that our subjective color perception is mediated by feedback from higher to lower level areas as well.

Subjective color vision is one of the most telling examples of what people generally believe to be a conscious process. Although in this experiment we did not manipulate attention or report, 7 out of 10 subjects were not aware of the goal of the study: subjects were informed that the study was about the combination of object and motion detection. Still, these 7 subjects displayed the same effect as the 3 subjects that were aware of the goal of the study (who were UvA employees). In addition, all subjects performed a fixation task, so their attention to the objects and the identity of the objects was minimal. This hints towards the conclusion that attention is not the mediating factor by which object knowledge influences color perception. However, as we did not manipulate attention such that subjects were not able to report about the objects, we cannot draw any conclusions on this matter. If the modulation of color perception found in this experiment would also occur when subjects are attentionally engaged in another task such that they cannot report about the objects, this would make a strong case for conscious processing of unattended and unreported stimuli.

Should we shift our focus in the study of consciousness?

One of the problems of studying consciousness is that it is entangled with a definition question. If one decides to equate consciousness with experience, it shouldn't matter whether a person can report about an experience or not, because the experience itself is what consciousness is about (Block, 2005, 2007; Crick & Koch, 1990; Koch & Tsuchiya, 2007; Lamme, 2006; 2010;

Tononi, 2008). If, however, ones definition of consciousness holds that reporting about what a person sees is crucial, then one will never accept unattended or unreported events as conscious, even if the brain activity underlying the unreported visual experience is exactly the same as that underlying the reported visual experience (Cohen & Dennett, 2011; Dehaene et al., 2006; Dehaene & Changeux, 2011; Kouider et al., 2010; Lau & Rosenthal, 2011). Therefore, instead of a shift in consciousness research, I propose an improved awareness of what it is we want to study: the mechanisms underlying report, or the mechanisms underlying the (visual) representation of our world.

In accordance with the findings presented in this thesis, many studies have shown that extensive visual processing can occur under unreported or unattended conditions (Kranczioch et al., 2005; Luck et al., 1996; Marois et al., 2004; Pitts et al., 2012; Sergent et al., 2005; Scholte et al., 2008). However, in these studies the main question often focuses on which mechanisms support the report of visual stimuli instead of how the visual representations come about. Although this is a crucial step in studying how we can maintain and manipulate information, it is less informative about the visual machinery that supports what we report about. To be able to have a visual experience, information first needs to be integrated on a visual level to create a percept. Then, if higher level areas are involved, the information is integrated such that manipulation and report of the visual percept are possible (Tononi, 2008). For example, if, in Chapter 6, we had measured the whole brain instead of only the visual cortex, we might have found differences in parietal or frontal areas between the group that could report about the Kanizsa figure and the group that couldn't (see e.g. Carmel et al., 2006). Crucially, however, the involvement of higher level areas did not qualitatively change processing in visual areas, and therefore, a disentanglement of the processes supporting visual perception and those supporting report is needed.

In the current thesis, I specifically investigated the mechanisms supporting qualitative visual processing. I have shown that many processes can occur outside focused attention: memory representations are formed, higher-level integration takes place, and unattended stimuli are explicitly available for decisions. This indicates that perceptual qualities can arise under conditions of inattention just as with attended processing. It thus seems that the only difference between attended and unattended processing is the extent to which the processes are strengthened so they are available for manipulation.

When we look around us, we experience a rich and integrated visual world. Although we are not able to report about everything we see, qualitative processing still occurs outside the scope of attention and report. This shows that our introspective feeling of seeing all that is in front of us is not an illusion, and that unattended representations form a real part of our visual experience. If we want to study how our visual experience comes about, we should not only focus on studying attended perception, but extend our study to include the qualities of unattended perception as well.