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The quality of perception without attention

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Publication date
2013

Citation for published version (APA):
Vandenbroucke, A. R. E. (2013). *The quality of perception without attention*.

Accurate metacognition for unattended visual representations

CHAPTER 5

Abstract

Our capacity to attend to multiple objects in the visual field is limited. However, introspectively we feel we see the whole visual world at once. Previous studies have suggested that the feeling of seeing more than we can attend to is illusory. Here, we investigated this by combining objective change detection performance with subjective confidence ratings during a visual memory task. This allowed us to compute a measure of metacognition, the degree of knowledge subjects have about the correctness of their perceptual decisions. We show that subjects not only store more objects than they can attend to, but that their metacognitive performance for the unattended objects is equal to metacognitive performance for attended representations. This suggests that our subjective impression is not an illusion, but accurately reflects the richness of our visual perception.

Introduction

In day-to-day life, we subjectively experience everything that is in our visual field as a rich and integrated whole. When asked about a scene that has disappeared from view, however, we can only report about the few items we happened to attend to. This dissociation between our rich experience and limited attentional capacities remains poorly understood. The introspective feeling of rich perception has been supported by partial-report studies (Landman et al., 2003; Sligte et al., 2008; Sperling, 1960), showing that for a brief moment after disappearance of a visual display, a cue can guide subjects to retrieve much more information from the display than when no cue is given. It thus seems that a lot of information is available for a short period after stimulus offset, but this information quickly decays over time. This temporary high-capacity memory storage has been taken to suggest that, actually, our conscious experience is not limited to what we can report about, but our limited attentional capacities restrict unattended information from being made robust and available for report and other cognitive manipulations (Block, 2005, 2011; Lamme, 2006, 2010). Others, however, argue that unattended items are never consciously processed, and that attention is necessary to have a visual experience (Cohen & Dennett, 2011; Kouider et al., 2010). In this view, our introspective feeling of seeing more than we can attend to is illusory and high-capacity performance in partial-report experiments is based on implicit or unconscious information (Lau & Rosenthal, 2011; Rahnev et al., 2011). In the present study, we investigated whether our subjective experience of perceiving more than we can attend to is real or illusory by combining objective with subjective ratings during a partial-report experiment, thereby measuring the level of metacognitive performance for unattended objects (Fleming, et al., 2010; Kanai, Walsh, & Tseng, 2010).

Previous studies have shown that when subjects attend away from a stimulus location, they adopt a liberal decision criterion for target stimuli in that location, tending to report that a stimulus is present. In contrast, when subjects attend to a stimulus location, they less often report that a stimulus is present, corresponding to a conservative decision criterion. In addition, the confidence ratings accompanying perceptual decisions are higher for unattended than for attended stimuli (Fig. 5.1; Rahnev et al., 2011; Rahnev, Maniscalco, Luber, Lau, & Lisanby, 2012; Wilimzig, Tsuchiya, Fahle, Einhäuser, & Koch, 2008). Although this seems counterintuitive, it can be explained within the framework of signal detection theory (Macmillan & Creelman, 2005): during attention and inattention a subjects' confidence criterion may remain the same, inattention introduces a more variable internal representation and thus a wider signal distribution, creating more responses that exceed the confidence threshold (Fig. 5.1). It has therefore been suggested that our subjectively rich perception is inflated and that actually very

little is seen outside the focus of attention (Rahnev et al., 2011). A crucial point that has been overlooked, however, is whether subjective confidence ratings coincide with objective performance. When correct responses are accompanied by high confidence and incorrect responses by low confidence, subjects have good knowledge about the correctness of their perceptual decisions, or high metacognitive performance (Fleming et al., 2010; Metcalfe & Shimamura, 1994). Vice versa, when there is no relationship between confidence ratings and the correctness of perceptual decisions, metacognition is low. Investigating subjective and objective ratings in isolation tells us something about the characteristics of decision criteria and confidence, but looking at metacognition reveals whether subjects base their objective decisions on explicit knowledge.
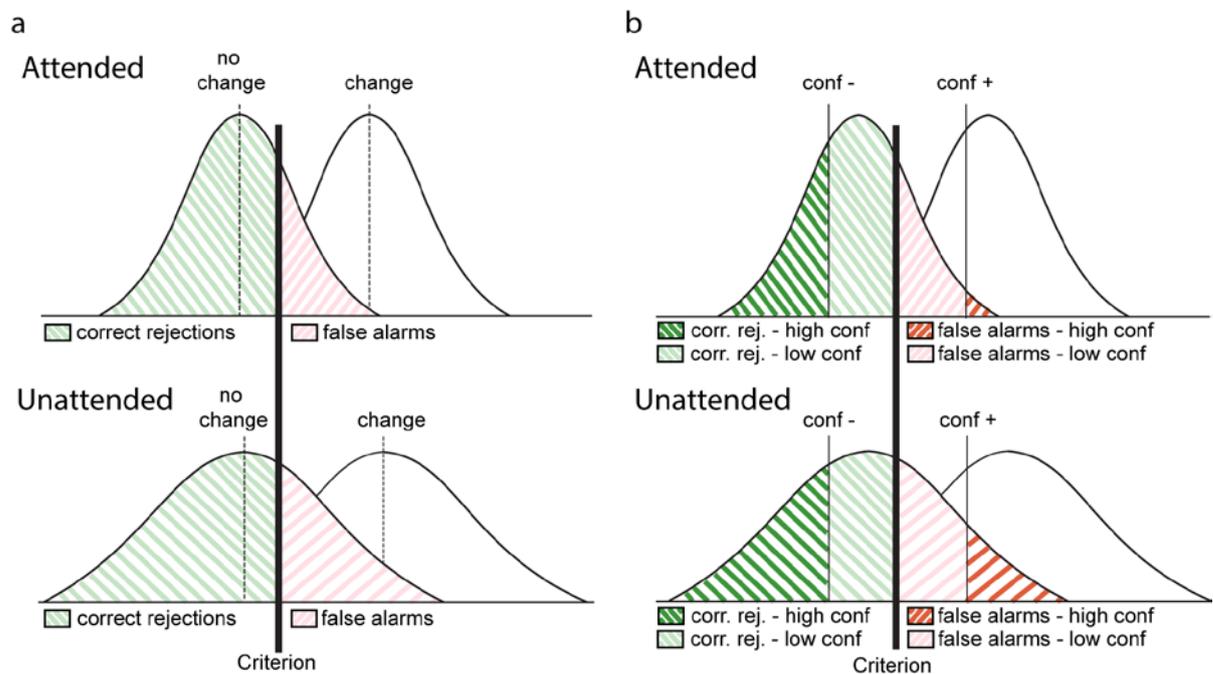

Figure 5.1. Signal detection diagrams under attended (upper panels) and unattended (lower panels) conditions. *Characteristics are described using a change detection paradigm, because we use this paradigm in Experiment 1 (To translate this diagram to classical signal detection theory, 'no change' can be replaced by 'stimulus absent' and 'change' by 'stimulus present'). (a) Hypothetical probability densities of signal strength induced by two stimuli in a change detection paradigm. In this case, a stimulus is presented that does not change. The probability densities of change and no change are normally distributed and are a certain distance apart. The distance between the peaks (in standard deviation units; also known as d') signals the discriminability between the two alternatives. The decision criterion (thick vertical line) is the threshold above which a subject responds change in a particular trial. When the decision criterion lies exactly in*

between the two peaks it will result in the same number of no-change and change responses (assuming equal variance). When the decision criterion is shifted towards either peak there will be a corresponding response bias; in this figure the decision criterion is negative (shifted towards the left peak) so that subjects respond change more often, resulting in more hits, but also more false alarms. When a stimulus is unattended (lower panel), there is more variance in the signal as compared to when the stimulus is attended (upper panel). This creates a wider signal distribution, but when the decision criterion remains the same, this will result in more change responses (again we assume equal variance), and thus a higher false alarm rate (Rahnev et al., 2011). *In (b), the effect of attention on confidence ratings is shown. When the signal is greater than the conf+ threshold or lower than the conf- threshold, subjects will give high confidence ratings (dark colored stripes); when the signal is in between conf- and conf+, subjects give low confidence ratings (light colored stripes). Conf- reflects the situation in which subjects have high confidence that the stimulus indeed did not change (thick red stripes), conf+ reflects the situation in which subjects have high confidence that the stimulus changed, when in fact it did not (thick green stripes). Again, in the absence of attention (lower panel) there is more variance in the signal (as compared to the upper panel). This results in a wider distribution and therefore the additional variance in the absence of attention will lead to a larger number of high confidence ratings, even when the confidence criterion itself does not change between attended and unattended stimuli.*

To investigate metacognition for unattended visual representations we combined a partial-report change-detection paradigm with subjective confidence ratings. By using a partial-report paradigm one can distinguish between visual sensory memory (Sperling, 1960) and visual working memory (WM; Luck & Vogel, 1997). Visual sensory memory is a high capacity memory storage in which information is maintained in a fragile format for a short period of time (Sligte et al., 2008). It can be divided into Iconic Memory (IM) and Fragile Visual Short-Term Memory (FM). IM is a high-capacity, short-lived store that is dependent on afterimages. FM on the other hand, is a form of memory that can last for up to 4 seconds (Sligte et al., 2008) and is supported by cortical processing (Sligte et al., 2009), but is fragile because it is overwritten by a new display containing similar items (Makovski et al., 2008; Pinto et al., 2013). WM on the other hand is a low-capacity, long-lived memory storage that is not overwritten by new displays (Baddeley & Hitch, 1986; Durstewitz, Seamans, & Sejnowski, 2000; Pinto et al., 2013). Crucially, WM capacity depends on attention (Awh et al., 2006; Chun, 2011), while FM capacity is hardly reduced when attention is diverted during encoding of the memory array (Vandenbroucke et al., 2011).

Since WM contains information we can manipulate and report about, it is thought to reflect conscious, explicit processing (Baars & Franklin, 2003; Lamme, 2006). Therefore, we compared metacognitive performance for WM with metacognitive performance for sensory memory: if representations in sensory memory reflect implicit information processing, metacognitive performance should be lower for sensory memory than for WM. If, however, the information stored in sensory memory is as explicit as information stored in WM, metacognitive performance should be equal for these memory stages.

Measures of metacognition are notoriously subject to biases and confounds (Galvin, Podd, Drga, & Whitmore, 2003), which we were careful to control for. First, to ensure that differences in subjective scores cannot be ascribed to differences in objective performance (Lau & Passingham, 2006), we adopted a staircase procedure in which objective performance in both sensory and WM conditions was kept at 75% by varying the number of items to remember. This allowed us to measure capacity differences between the three types of memory, while keeping task difficulty the same. Second, we applied a recently introduced measure, meta-d'-balance (Maniscalco & Lau, 2012), that complements standard signal-detection analysis to ensure that metacognitive scores were not confounded by variation in objective or subjective decision criteria.

In Experiment 1, subjects performed a change detection task in which they reported whether a change in stimulus orientation occurred between a memory and a test display. We found that metacognition for sensory memory was equal to (IM) or even higher (FM) than metacognition for WM. In addition, subjects adopted a more liberal decision criterion for sensory memory than for WM, i.e., in sensory memory conditions subjects reported perceiving a change more often (Fig 5.1). This matches with the decision criterion as found by Rahnev et al. (2011) for unattended versus attended stages respectively, confirming our previous findings that FM, and also IM, represents an unattended stage of memory processing, while WM reflects attended processing (Vandenbroucke et al., 2011). At the same time, the differences in decision criterion between conditions, combined with the high hit and/or false alarm rates observed in this experiment, might have influenced metacognition scores (Barrett et al., submitted). We therefore conducted a second experiment in which we equalized the objective decision criterion. Subjects had to perform a discrimination task instead of a detection task: stimuli always changed orientation, and subjects had to indicate whether they perceived a clock-wise or counter-clockwise change. In this task, there was no bias towards reporting clock-wise or counter-clock wise, because under the signal detection theory, these two stimuli (and thus their thresholds) are interchangeable. We found that metacognition was now equal for sensory memory and WM,

and because the decision criterion was close to 0 and equal for all three memory conditions, the comparison of metacognitive scores for IM, FM and WM was fully warranted.

Experiment 1

Methods

Participants

Twenty-five students (with normal or corrected-to-normal vision) of the University of Amsterdam participated in the experiment (9 men, age M = 21.5, SD = 1.9). Subjects gave their written informed consent before the start of the experiment, which was approved by the local ethics committee.

Stimuli

The stimulus displays consisted of white rectangles (1.55° x 0.40° in visual angle) on a black background, placed randomly in placeholders (2.03°) of a 36 (6x6) squared grid (12.24° by 12.24°). The four placeholders surrounding the fixation dot (radius 0.23°) always remained blank. The rectangles had four possible orientations: horizontal, vertical, 45° to the horizontal or 135° to the horizontal. The cue consisted of four triangles (short sides 0.23°) positioned in the corners of a placeholder (Fig. 5.2).

Task

Subjects fixated on a centrally presented dot throughout each trial. The fixation dot changed from red to green for 1000 ms to indicate the start of a trial. Then, a memory display was presented for 250 ms containing differently oriented rectangles. Subjects were instructed to remember as many oriented rectangles as possible.

In the sensory memory conditions, a 500 ms-cue was presented either 50 ms (IM) or 1000 ms (FM) after offset of the memory display to single out the item to remember (Fig. 5.2a and c). The test display was then presented 500 ms after offset of the cue and subjects had to indicate whether the cued item had changed orientation or not (50 % change, 90˚ rotation, cue was always valid). In the WM condition, the test display was presented 900 ms after offset of the memory display and then the cue was presented 100 ms after onset of the test display to single out the item that might have changed orientation (Fig. 5.2b and c). After subjects gave their objective rating (change or no-change), they were asked to judge the confidence in their perceptual decision by choosing 'sure', 'doubt', or 'guess'. Subjects were encouraged to use all three options throughout the experiment.
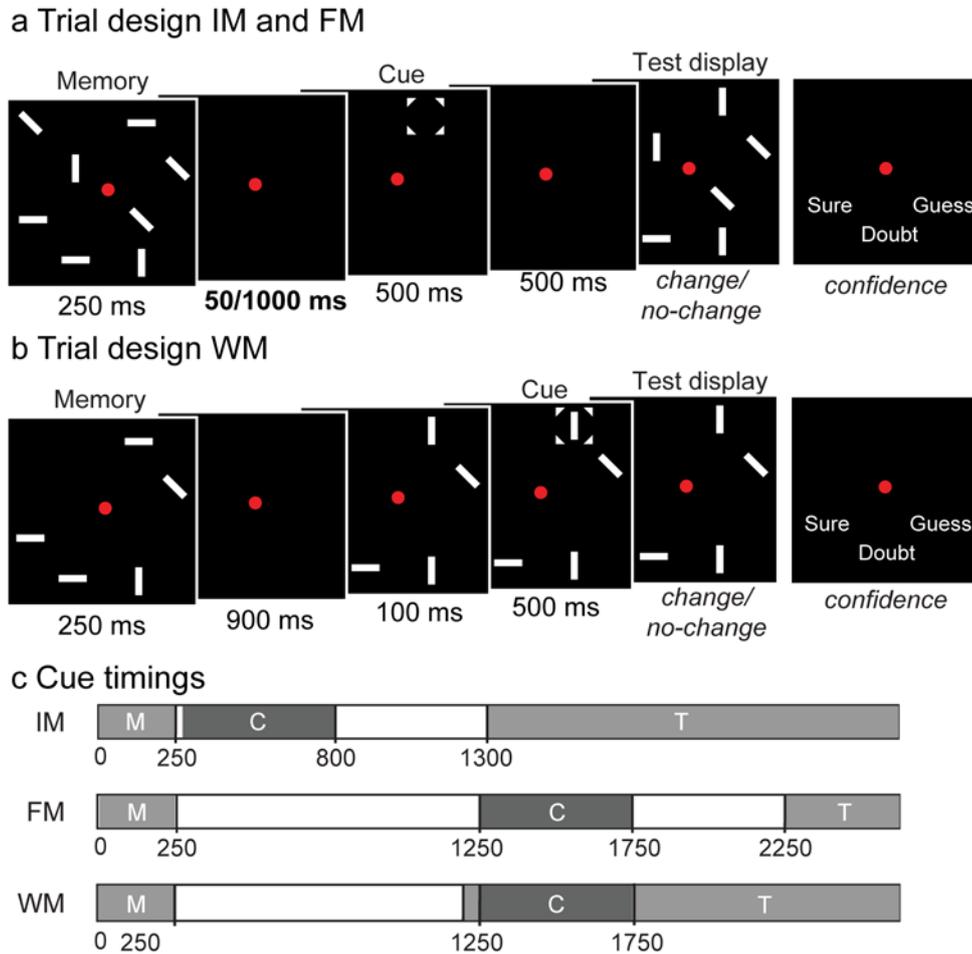
Figure 5.2. Trial design for Visual Sensory Memory (IM and FM) and Visual Working Memory (WM). *Subjects were presented with a memory display containing a number of items depending on their performance (staircase: performance was titrated to 75% by adding or removing rectangles). In the sensory memory conditions (a), a cue was shown after offset of the memory array but before onset of the test display. This allowed subjects to retrieve the information that was maintained before interference of a new display and resulted in a larger number of rectangle orientations that could be remembered. Two cue timings were used for the sensory memory condition (c, see text). In the WM condition (b), the cue was presented after offset of the test display, allowing subjects to retrieve only those items that were attended in the memory array and thereby made robust to interference from the test display. Cue and display timings were matched to IM and FM (c). Note that distances and relative sizes are adjusted for the purpose of illustration.*

Procedure

Before the start of the experiment subjects received a training of 60 trials (due to a technical mistake 5 subjects received 10-30 training trials more). IM, FM and WM trials were randomly

intermixed (20 trials each) and subjects were not informed about trial type. During training, the displays contained six randomly placed rectangles. Subjects received immediate feedback on the correctness of their (objective) response (confidence judgements were not elicited during training).

Previous studies have shown that capacity for IM and FM is much higher than for WM (Sligte et al., 2008; Vandenbroucke et al., 2011), and there are large individual differences. To minimize large variance in performance at the beginning of the experimental blocks (see below) for the different conditions, the number of rectangles in the displays at the outset of each experimental block was derived from the percentage correct on the training trials. The starting number of rectangles was calculated for IM, FM and WM separately (training trials 75 % correct: number of rectangles was kept at 6, every 15% deviance from 75% resulted in 1 rectangle more or less).

After training, subjects performed an experimental block of 366 trials (of which the first 6 were not analysed) in which the immediate feedback was eliminated and subjects additionally provided confidence judgements (2 subjects received 306 trials). To keep objective performance the same on all conditions and constant over the course of the block, percentage correct was calculated on every 4 trials (per condition) and a rectangle was added to or removed from the displays when performance was higher or lower than 75%. This resulted in an average performance of 75% for all three conditions, but a different capacity score, which was defined by the number of rectangles present in the display at the end of the experimental blocks (Fig. 5.3b).

Results

To evaluate whether objective performance was equal for IM, FM and WM, sensitivity was calculated as type I d' (z(hit rate) - z(false alarm rate), (Green & Swets, 1966; see Fig. 5.1). Hits were classified as correctly reported changes and false alarms as incorrectly reported changes. We excluded one subject from the analyses, because due to a technical mistake, this subject performed the task twice in a row and performance dropped throughout the second run. Figure 5.3a shows that – as intended - d' for FM and WM did not differ (t(23) = -.9, p = .380), but d' for IM was slightly higher, especially compared to FM (t(23) = 3.4, p = .002; main effect of memory conditions (F(2, 46) = 4.4, p = .018). Exploring the performance level for each condition over the course of the experiment showed that a few subjects kept on improving their score for IM throughout the experiment. This suggests that the IM condition was easier than the FM and WM conditions, and therefore, d' over the whole experiment was somewhat higher. The manipulation of keeping performance at the same level resulted in a different number of

rectangles in the displays at the end of the experiment for each of the three conditions (Fig. 5.3b; $F(2,46) = 29.5$, $p < .001$). This showed that the capacities for the three conditions differed, such that IM capacity was higher than FM capacity ($t(23) = 2.4$, $p = .026$), which was higher than WM capacity ($t(23) = 6.5$, $p < .001$).

To calculate decision bias, the decision criterion (See Fig. 5.1) was computed as c (-0.5*(z(hit rate) + z(false alarm rate); Green & Swets, 1966; Fig. 5.3c). The decision criterion was negative for both sensory memory conditions, showing that there was a tendency to respond 'change' more often than 'no-change', while in the WM condition, the opposite occurred ($F(2,46) = 132.7$, $p < .001$). Thus, for sensory memory a more liberal decision criterion was adopted while for WM, the criterion was more conservative.

The level of metacognitive performance was established by plotting and analyzing the type II Receiver Operating Characteristic (ROC) curve (Fig. 5.3d). This plots the cumulative probabilities of the confidence ratings for correct responses versus the cumulative probabilities of the confidence ratings for incorrect responses (Macmillan & Creelman, 2005). The Area Under the (ROC) Curve (AUC, deviation from the diagonal) then provides a measure of the ability to link confidence to perceptual performance (Galvin et al., 2003; Fleming et al., 2010). The AUC for the three conditions differed ($F(2,46) = 4.5$, $p = .013$), and this effect was mainly driven by the fact that the AUC for FM was larger than for WM ($t(23) = 3.3$, $p = .003$). This shows that there is at least as much metacognition for IM as for WM (AUC for IM versus WM gave $t(23) = 1.5$, $p = .14$), and suggests even higher levels of metacognition for FM.
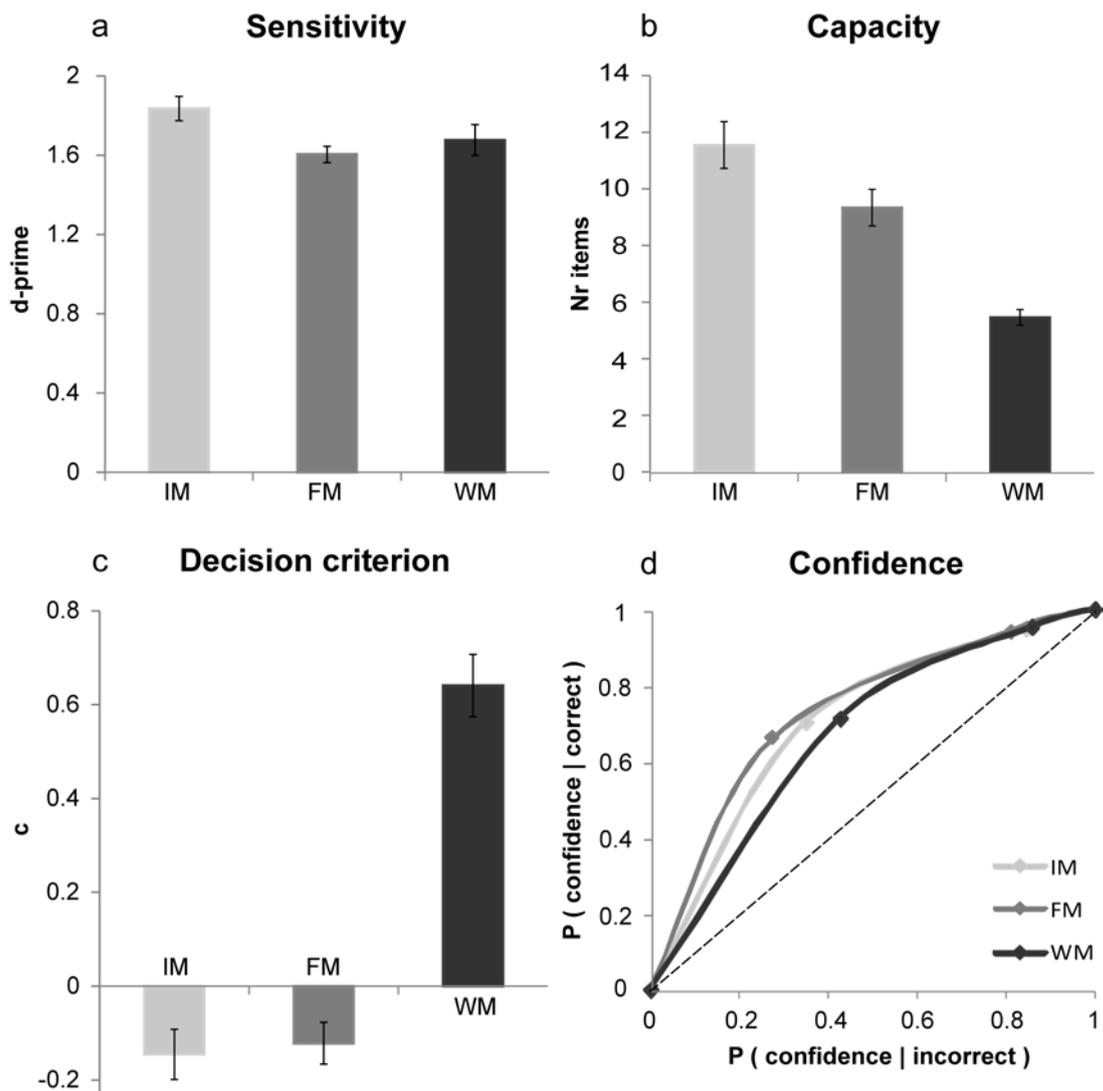
Figure 5.3. Results Experiment 1. *(a) To prevent objective performance from influencing metacognitive performance, objective performance was titrated to 75% using a staircase procedure that adjusted the amount of items to remember. As a result, sensitivity (d') was around 1.6 in all conditions, although IM had a somewhat higher sensitivity than FM. (b) Capacity scores, as defined by the number of rectangles displayed at the end of the experimental blocks. Capacity for IM was higher than for FM, which in turn was higher than capacity for WM. (c) Decision criterion c (in standard deviation units) for IM and FM versus WM stages. Both sensory memory conditions were characterized by a more liberal decision criterion, showing that subjects reported a change more often. (d) Confidence ratings (1-3) were used to derive a Receiver Operating Characteristic (ROC) curve that shows the ability to discriminate between incorrect and correct responses for each level of confidence. The four points plotted are the rates of type II hits (confident when correct) and false alarms (confident when incorrect) when (i) only `sure' responses are classified as `confident'; (ii) both `sure and `doubt' responses are classified as*

`confident'; (iii) all responses are classified as `confident' (1,1); (iv) no responses are classified as `confident' (0,0). These four points correspond to different confidence thresholds on the signal-detection theory model (Fig. 5.1). The Area Under the Curve (AUC, deviation from the diagonal) was equal for IM and WM, while it was significantly larger for FM compared to WM, showing that metacognitive performance was equal to or higher for sensory memory than for WM.

Although from these data one might conclude that metacognition for sensory memory is similar to or even higher than metacognition for WM, it has been shown that (type I) decision criterion can influence metacognition scores based on the AUC (Barrett et al., in press; Maniscalco & Lau, 2012). Therefore, we also calculated meta-d'-balance, a newly developed measure of metacognition that is less sensitive to decision criteria variation (Barrett et al., submitted). This measure is defined as the type I d' that would have led to the observed type II data on the standard signal-detection theory model (Fig. 5.1) and extends a recent previous measure, meta-d' (Maniscalco & Lau, 2012) by admitting a unique solution given type I and type II data. When we included all subjects, the results for these analyses were similar to those obtained from the ROC analysis (see Table 5.1), showing that FM had a higher metacognition score (Meta-d'-balance) than IM and trended towards a higher metacognition score for WM. Taken together, these analyses suggest that metacognition for sensory memory is similar to or even higher than metacognition for WM.

However, although meta-d'-balance is robust to variation in decision criterion, it can still deliver unstable estimates for extreme hit and false alarm rates (<0.05 or >0.95, see Barrett et al., submitted). When we excluded subjects with estimated responses in these ranges, only 3 subjects remained in the WM condition. Therefore, in order to rigorously compare levels of metacognition under WM and sensory memory conditions, we conducted a second experiment which was designed to maintain decision criteria closer to 0 (i.e. zero response bias, see Fig. 5.1) in all three conditions.

	All subjects included (Narrow exclusion criterion)			Only stable subjects included (Wide exclusion criterion)		
	Meta-d'-balance (N)	*SD*	*Comparisons to: (unpaired t-test)*	*Meta-d'-balance (N)*	*SD*	*Comparisons to: (unpaired t-test)*
IM	1.13 (24)	1.06	FM: p = .04 WM: p = .78	0.64 (13)	0.11	FM: p = .81 WM: p = .72
FM	2.04 (24)	1.84	IM: p = .04 WM: p = .08	0.70 (9)	0.19	IM: p = .81 WM: p = .80
WM	1.23 (24)	1.30	IM: p = .78 FM: p = .08	0.53 (3)	0.40	IM: p = .80 FM: p = .72

Table 5.1. Meta-d'-balance results for Experiment 1. *Using the two sets of criteria for subject exclusions as suggested by Barrett et al (submitted; Narrow exclusion criteria include all subjects with all estimated hit and false alarm rates strictly greater than 0 and strictly less than 1, and wide exclusion criteria only include subjects with all estimated hit and false alarm rates >0.05 and <0.95, specified as N.) Meta-d'-balance analysis gives similar results to the AUC analysis and supports the conclusion that there is at least as much metacognition for IM and FM as for WM. However, under the narrow exclusion criterion estimates are rather variable (large SD) and extreme detection criteria caused many unstable estimates, especially in WM. Only 3 subjects remained when the wide exclusion criterion was used.*

Experiment 2

Experiment 1 showed that metacognition for sensory memory was equal to (IM) or higher (FM) than metacognition for WM when measured both by AUC and by meta-d'-balance. However, variation in the decision criterion might have affected metacognition scores (Barrett et al., in press; Maniscalco & Lau, 2012). To better compare metacognition for the three memory types, we conducted a second experiment in which we equated decision criteria by substituting the change-detection task with a change-identification task. The rectangles were replaced by arrows and the cued arrow always changed orientation between memory and test display. The subjects' task was now to indicate whether the change in orientation was clockwise or counter-clockwise. Because this was not a detection task in which the stimulus had to pass a certain threshold to be reported as seen (see Fig. 5.1), there was no reason to assume that there should be a bias between responding clockwise or counter-clockwise. The decision criterion should therefore be closer to 0 (i.e. small response bias) and be roughly equal for attended (WM) and unattended (IM, FM) representations.

Methods

Participants

Twenty-four students (with normal or corrected-to-normal vision) of the University of Amsterdam participated in the experiment (3 men, age M =22.0, SD = 0.6). Subjects gave their written informed consent before the start of the experiment, which was approved by the local ethics committee.

Task, Procedure & Stimuli

The task and procedure were exactly the same as in Experiment 1, except now subjects had to indicate whether a cued arrow had changed orientation clockwise or counter-clockwise. The arrows (1.20˚x 0.63˚) were oriented up, down, to the left or to the right (see Fig. 5.1; layout of the displays was the same, except now, rectangles were substituted by 4 differently oriented arrows). The change always consisted of a 90˚ rotation.

Results

The manipulation of keeping objective performance the same was successful and d' (hits were classified as correctly reported counter-clockwise changes and false alarms as incorrectly reported counter-clockwise changes) for the three memory conditions was equal (Fig. 5.4a; $F_{(2,46)}$ = 1.6, p = .205), while capacity scores differed (Fig. 5.4b; $F_{(1.4,32.6)}$ = 7.2, p = .006, Greenhouse-Geisser corrected). Differently than in Experiment 1, there was no difference between IM capacity and FM capacity ($t_{(23)}$ = -.5, p = .634), but only a difference between IM and FM with WM capacity (IM vs WM: $t_{(23)}$ = 4.9, p < .001; FM vs WM: $t_{(23)}$ = 3.0, p = .007), still showing the crucial phenomenon of a higher capacity for IM/FM than for WM. As expected, the decision criterion was now also the same for each memory condition (Fig. 4c; $F_{(2,46)}$ = .7, p = .513) and therefore, the comparison between metacognition scores for each memory condition using AUC and meta-d'-balance can be fully justified (Barrett et al., submitted).
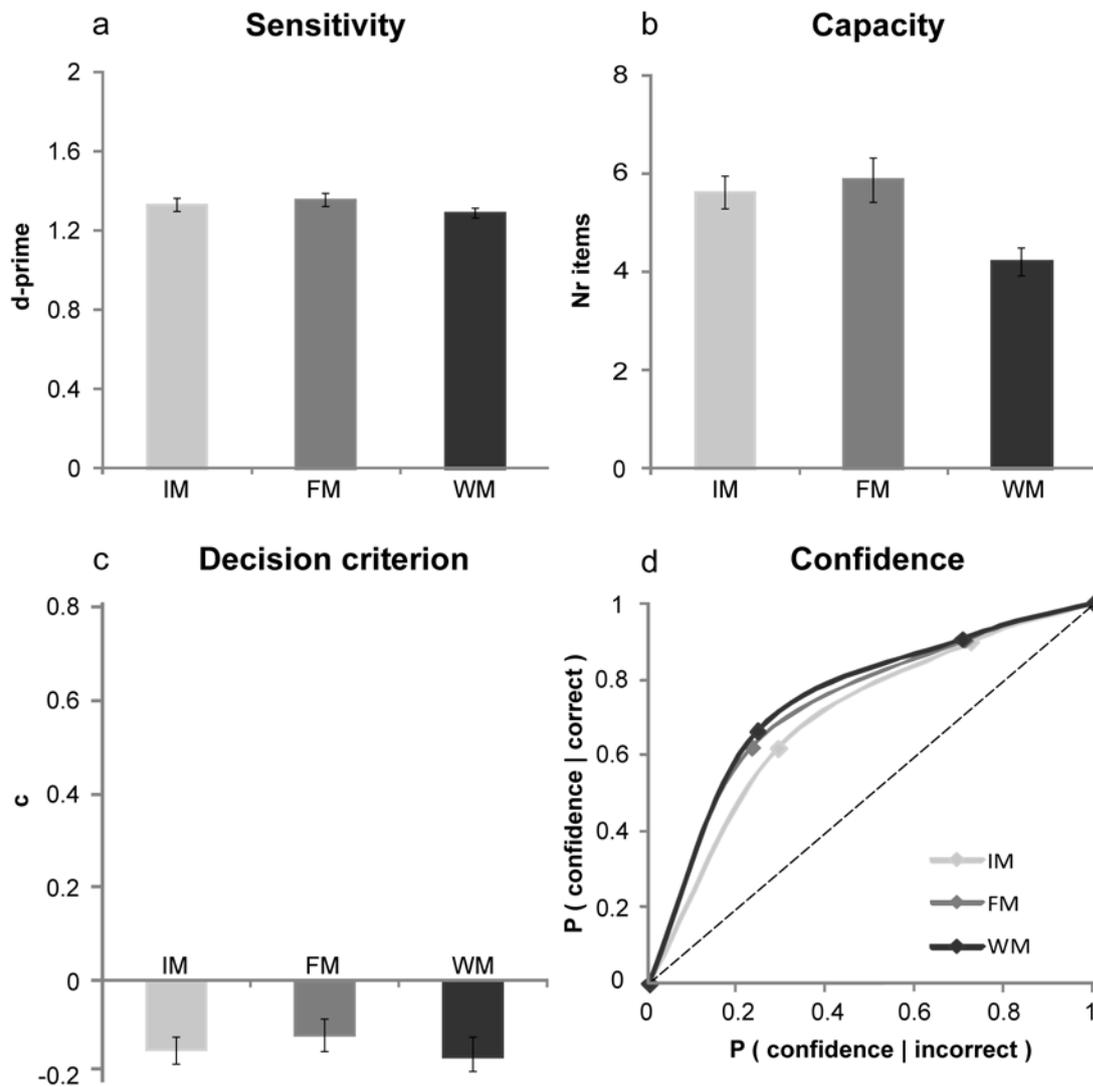
Figure 5.4. Results Experiment 2. *(a) To prevent objective performance from influencing metacognitive performance, objective performance was fixed at 75% using a staircase procedure that adjusted the amount of items to remember. As a result, sensitivity (d') was around 1.3 in all conditions. (b) Capacity scores as defined by the number of rectangles displayed at the end of the experimental blocks. Capacity for IM and FM were higher than capacity for WM. (c) Decision criterion c (in standard deviation units) for the three memory stages was the same. A negative decision criterion here reflects that subjects had the tendency to report a clockwise rotation more often than a counter-clockwise rotation. (d) Confidence ratings (1-3) were used to derive a Receiver Operating Characteristic (ROC) curve that shows the ability to discriminate between incorrect and correct responses for each level of confidence. The Area Under the Curve (AUC) for FM was equal to WM, suggesting that metacognitive performance was equal. The AUC for IM was significantly smaller than for WM.*

Metacognition scores as calculated by the AUC of the ROC (Fig. 5.4d) were just significantly different for the three memory conditions ($F(2,46) = 3.2$, $p = .049$). This was driven by the fact that metacognition for IM was lower than for WM ($t(23) = -2.3$, $p = .030$). Metacognition for FM and WM, however, were now the same ($t(23) = -.6$, $p = .531$), showing that when controlling for objective sensitivity and decision criteria, FM and WM are equally based on explicit processing.

	All subjects included (Narrow exclusion criterion)			Only stable subjects included (Wide exclusion criterion)		
	Meta-d'-balance (N)	SD	Comparisons to: (unpaired t-test)	Meta-d'-balance (N)	SD	Comparisons to: (unpaired t-test)
IM	1.05 (24)	1.48	FM: p = .35 WM: p = .15	0.71 (20)	0.47	FM: p = .33 WM: p = .31
FM	1.42 (24)	1.27	IM: p = .35 WM: p = .50	0.86 (14)	0.42	IM: p = .33 WM: p = .93
WM	1.71 (24)	1.64	IM: p = .15 FM: p = .50	0.88 (18)	0.52	IM: p = .31 FM: p = .93

Table 5.2. Meta-d'-balance results for Experiment 2. *When all subjects are included (all estimated hit and false alarm rates > 0 and < 1), results are similar to metacognition as calculated by the AUC: metacognition for FM and WM are equal and metacognition for IM is on average lower, but standard deviations (SD) are large due to instabilities and there is no significant difference. When the wide exclusion criterion is used (all estimated hit and false alarm rates > .05 and < .95), more participants remain than in Experiment 1 (IM: 20 compared to 13, FM: 14 compared to 9, WM: 18 compared to 3) and there is no significant difference in the observed distribution of meta-d' between the three memory conditions.*

Using meta-d'-balance we found similar results, indicating that metacognition for FM and WM were the same, while metacognition for IM tended to be lower (Table 5.2). In addition, when using a wide exclusion criterion, fewer subjects were excluded compared to Experiment 1, confirming that there were fewer extremely response-biased subjects in Experiment 2 compared to Experiment 1.

Discussion

In this study, we investigated whether unattended objects are explicitly or implicitly processed by measuring metacognitive performance in a partial-report change-detection task. Using a signal-detection theory framework, we obtained metacognition scores for early and late stages of sensory memory (IM and FM), which are high-capacity forms of memory that reflect unattended processing. We compared these to metacognition for WM, a low-capacity, explicit and attention-dependent form of memory. While objective performance (d') was equal for IM, FM and WM, capacity measures for IM and FM were higher than for WM. At the same time, metacognitive performance for FM was higher than (Experiment 1) or equal to (Experiment 2) metacognitive performance for WM. This shows that the higher capacity found for FM is not based on implicit, unconscious information, but reflects conscious, explicit information processing.

In Experiment 1 the decision criterion for IM and FM was much more liberal than for WM; subjects more often reported perceiving a change in the sensory memory conditions than in the WM condition. This finding matches earlier findings that the decision criterion for unattended representations is more liberal than for attended representations (Rahnev et al., 2011; Rahnev, Maniscalco, Luber et al., 2012), and thereby further supports the claim that IM, FM and WM capacity reflect different stages in visual short-term memory (Block, 2011; Lamme, 2010; Sligte et al., 2008; Vandenbroucke et al., 2011). However, since decision criterion might influence metacognitive scores when combined with extreme hit rates and false alarm rates, we conducted a second experiment in which both the decision criterion and sensitivity were equated over conditions.

When the decision criterion and sensitivity were constant across conditions (Experiment 2), metacognition for FM was equal to metacognition for WM, but metacognition for IM was lower. This suggests a deviation between IM and FM in their dependence on explicit information processing. Possibly, the mechanisms underlying IM are partly implicit. This might also explain why for Experiment 1 (detection), IM capacity was higher than FM capacity, while for Experiment 2 (discrimination), capacity for IM was equal to FM. Discriminating which type of orientation change occurred might be more complex and dependent on explicit processing compared to simply detecting orientation changes (Clifford & Harris, 2005). The results of this study therefore suggest that FM has a larger capacity than WM and at the same time depends on explicit processing just as WM, while the larger capacity found for IM might partly depend on implicit processing.

The results of the current study are in line with a previous study showing that FM is perceptual in nature (Vandenbroucke et al., 2012): when subjects have to remember illusory triangles (Kanizsa figures) versus unbound control figures (in which the same inducers are rotated), there is a benefit for both FM and WM. In addition, identification of real-life objects is also possible in FM (Sligte et al., 2010). Together, these studies suggest that what we perceive outside attention is perceptually rich, and that our subjective impression is as accurate for unattended as for attended representations.

Conclusion

Previous studies have shown that for unattended versus attended objects, the decision criterion is more liberal and subjective confidence ratings are inflated (Rahnev et al., 2011; Wilimzig et al., 2008). This has led researchers to suggest that our perception outside attention is supported by a false impression and might even be illusory (Rahnev et al., 2011). In this study, we showed that although the decision criterion for unattended items might be more liberal than for attended items, metacognitive performance - as measured by the combination of subjective and objective scores - is equal for unattended and attended objects. As objective performance was equalized over conditions, one has to conclude that the high capacity scores found for sensory memory, at least when using late-timed cues that measure FM, reflect explicit information processing in the same way that low-capacity WM reflects explicit information processing. Thus, unattended representations are a realistic, and possibly consciously processed, part of our rich visual experience.

Acknowledgements