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Dynamic re-calibration of perceived size in fovea and periphery through predictable size changes

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Summary

The same object produces quite distinct images in the cortical representation, depending on whether it is looked at foveally or with the periphery, yet some form of size constancy prevents us from experiencing objects inflating or deflating as we move our eyes. According to the prominent sensorimotor account of vision by O'Regan and Noë[1], we constantly learn to discount the predictable sensory effects of motor actions, such as the projection of a stimulus on a larger cortical area as it gets foveated. While previous studies have shown that foveal and parafoveal inputs can be associated in visual memory [2, 3], trans-saccadic prediction error could in principle re-calibrate even the appearance of peripheral and foveal stimuli. Here we introduce a new paradigm that induces such changes in the relative appearance of peripheral and foveal stimuli when directly compared. Repeated exposure to a trans-saccadic change in size, though unnoticed by most observers, induced a substantial modification of perceived size which lasted at least one day. Prediction is not limited to the motor system, but can also occur for the sensory effects of external events, such as stimulus motion. We show that perceptual re-calibration can occur in the absence of eye movements if the change in size occurs predictably while objects move across the visual field. Perceptual uniformity emerges due to the continuously updated prediction of foveal appearance based on peripheral appearance.

Results and Discussion

Main experiment: re-calibration of appearance

In each trial, observers first compared the size of two approximately circular stimuli, one viewed centrally and one viewed peripherally (Figure 1A). After giving their judgment, they made a saccade to the peripheral stimulus. During the saccade, its size could be decreased or increased by 10%. Over the course of the first session of the experiment the trans-saccadic manipulation induced a corresponding change in the perceived size of the peripheral stimulus compared to the foveal one, as indexed by the change in the Point of Subjective Equality (PSE) during the course of the experiment (see Figure S1 and Supplemental Experimental Procedures for details). For example, after being exposed to a 10% decremental trans-saccadic radius change for 300 trials, the perceived radius of the peripheral stimulus decreased by 7% relative to the foveal stimulus, nearly matching the physical size change (Figure 1C). The curve from the increase group does not show an overall change. However, a comparison between both curves and the curve of the control group, who was not exposed to any trans-saccadic change, suggests that re-calibration was induced both by size increases and decreases. The reasons for this generic trend towards a PSE decrease in the first 200 trials is most likely the well-known tendency to report peripheral stimuli as appearing slightly smaller [e.g 4], coupled with our adaptive-staircase procedure which can take a few dozens of trials before accommodating the stimulus range to a biased PSE.

On the second day, we reversed the manipulation for each group of observers, and accordingly, appearance was re-adjusted (Figure 1D). The perceived size adjustment can be summarized as the rates of size change (Figure 1E), which differed significantly between the *Decrease* and *Increase* groups on both days (Day 1: $t(30)=3.724$, $p<.0016$; Day 2: $t(30)=5.219$, $p<.001$, both Bonferroni corrected). As expected, it reversed between Day 1 and Day 2 ($F(1,30)=42.12$, $p<.001$). Importantly, the initial PSE value differed between the groups on Day 2 ($t(30)=3.04$, $p<.005$), indicating a long-lasting effect of the training on the previous day. This could suggest that the learning is limited to the specific context in which it took place, in particular since similar learning phenomena [3, 5, 6] have been shown to be object-specific. Notice however that saccadic adaptation, for example, is both context-independent [e.g. 7] and long-lasting [e.g. 8].

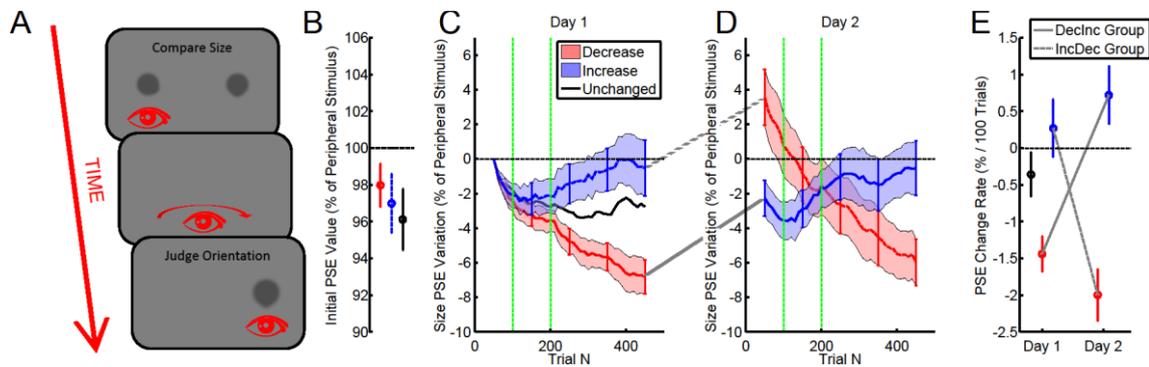


Figure 1. Experimental Task in the main experiment. A: *Experimental Procedure.* Observers first compared the size of the central and peripheral stimulus. Subsequently they looked at the peripheral stimulus and judged its orientation. Both judgments and the eye movement were unspeeded. During the saccadic eye movement the size of the stimulus could increase or decrease by up to 10%. See *Supplemental Experimental Procedures* for details. B-E: *Time-course of the change in perceived size (stimulus radius) throughout the main experiment.* B: initial value of the PSE computed in the first 100 trials where no trans-saccadic change took place. C and D: variation in the PSE relative to each observer's initial value. The vertical green dashed lines denote the 100th trial, where the size change was introduced and the 200th trial where it reached its full extent of $\pm 10\%$. Shaded areas and error bars are SEM. The colored error bars spaced by 100 trials denote size estimates computed on completely separate subsets of trials and thus independent, while intermediate estimates are computed on partially overlapping subsets of trials. After the 200th trial, the PSE values start diverging, indicating that the exposure to a manipulation of the post-saccadic size produces the predicted change in the pre-saccadic size appearance. Solid and dashed lines identify the *Decrease-Increase* and *Increase-Decrease* groups, respectively. E. Average rate of change in perceived size as a function of Day.

Post-session: re-calibration spreads to the opposite hemifield.

In the experiment above, testing was performed only at the location where the size change was introduced. Perceptual learning processes were often shown to be entirely local[9], but recently there has been some evidence that generalization is possible in some cases[10, 11]. In order to investigate the possible transfer of re-calibration to untrained locations, sixteen of the observers also underwent post-sessions in which apparent size was tested without any further saccades. The observers judged size both at the location of the saccadic target during training and in the opposite

hemifield, and did not direct their gaze at the peripheral stimulus afterwards. The corresponding PSE values, taking into account each observer's initial baseline level, are presented in Figure 2. The results in the two post-sessions mirror quite closely the situation at the end of the preceding training sessions at both locations.

We submitted the PSE variation data to a 3-way ANOVA (Location: Same vs. Different, Group: Declnc vs. IncDec, Day: 1 vs. 2). The Group by Day interaction was significant ($F(1,14)=126.039, p<.001$), indicating that the effects of learning are still measurable when no saccades are performed. Crucially, the three-way interaction ($F(1,14)=1.937, p=.186$), as well as all other main effects or interactions (all $ps>.15$) were not significant. Overall, the results indicate that the learning is transferred equally to both sides of the visual field and is not local. Our size comparison method for testing appearance does not distinguish between changes in local size representation, whether foveal or peripheral, and changes to a more general central-peripheral size scaling mechanism. One possible reason for having a symmetrical size-scaling mechanism could be that cortical magnification predicts a relatively uniform geometrical distortion in cortical projection as a function of eccentricity [12-14]. This suggests that a relatively high-level perceptual mechanism is responsible for the trans-saccadic re-calibration. After all, while there is ample evidence associating perceived size to cortical projections starting from V1[15-18], the trans-saccadic re-calibration process would be in place precisely to compensate for the geometrical distortions in early visual areas.

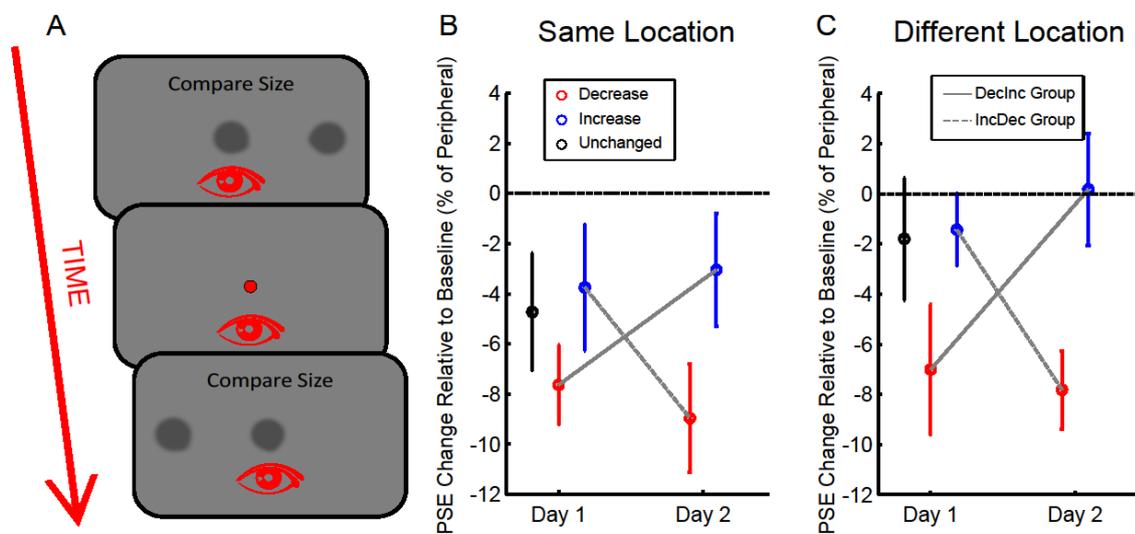


Figure 2. Procedure and perceived size values in the post-sessions. PSE values are expressed as change relative to baseline. In the post-session the peripheral stimulus appeared alternatively on the same side where it had appeared during the training session (data in B) and on the opposite side (data in C) and the observers did not execute any saccades or orientation judgments. The effect of the training seems still evident in the post-tests, notice in particular how the relative magnitude of the PSEs is reversed between Day 1 and 2 across groups. Moreover, there is no evidence that the effect of learning is stronger when the trained hemifield was tested as opposed to the untrained one.

Reverse change experiment: No re-calibration

The situation in our experiments closely mimics the dynamics of fovea-periphery associations in everyday life. First, we see an object in the periphery, then we make a saccade towards the object and see it foveally. In principle, we can also associate two objects in the reverse sequence. After the saccade, the object that was previously in the fovea is now in the periphery. A size change in this object during the saccade might lead to the same learning processes.

Another 16 observers were tested in a modified version of the paradigm. Like in the main experiment, the observers compared the size of a centrally viewed and a peripherally viewed stimulus, but after the saccade the saccadic target disappeared and the previously fixated stimulus was still visible in the periphery where its size could be modified. Between 50 and 1050 ms following the re-appearance of the now peripheral stimulus, its shape changed for one frame (16 ms) to an oriented shape similar to the ones used in the other experiments. Observers were informed that this change could only occur in this time frame, so that if they had not perceived any change relatively soon after stimulus onset they were supposed to guess its orientation. Given that preliminary data suggested that the oriented stimulus might be less visible if presented just after the saccade, four separate staircases determined the amplitude of the oriented protrusion based on its onset delay (50-300, 300-550, 550-800 und 800-1050 ms).

Unlike the exposure to a trans-saccadic change in the saccadic target size, the change in the formerly fixated stimulus failed to induce any systematic re-calibration of perceived size (see Figure 3). In order to perform an overall test for the presence of re-calibration, we submitted the rate of change values to a two-way ANOVA with Group (IncDec vs. Declnc) and Day (1 vs.2) as factors. None of the main effects nor the 2-way interaction turned out significant (all $p > .3$), suggesting that the exposure to modified peripheral feedback did not modulate the spontaneous tendency to PSE decrease. Notice that the non-significant numerical trend for an interaction observed in Figure 3 is the opposite of what would be expected had re-calibration taken place. An increase in the size of the stimulus between foveal and peripheral vision would have induced a relative reduction in the perceived size of the peripheral stimulus had re-calibration taken place. We further submitted the rate of change data from the main experiment and from the reverse change experiment to a combined three-way ANOVA with Day (1 vs. 2) as a within observers factor and Group (IncDec vs. Declnc) and Experiment (Main vs. Reverse Re-calibration) as between observers factors. This yielded a significant three-way interaction ($F(1,44)=22.88, p < .001$), confirming that there is less – if any – re-calibration in the reverse change experiment.

Objects that are viewed peripherally after the saccade do not influence size perception. One explanation of the discrepancy between this result and what we observed when we changed the size of the saccadic target might be in terms of attention. It is well known that visual attention is to a large degree bound to the saccadic target [19]. Therefore fewer resources might have been allocated to the previously fixated stimulus, even though our observers were explicitly required to keep tracking its possible shape variations.

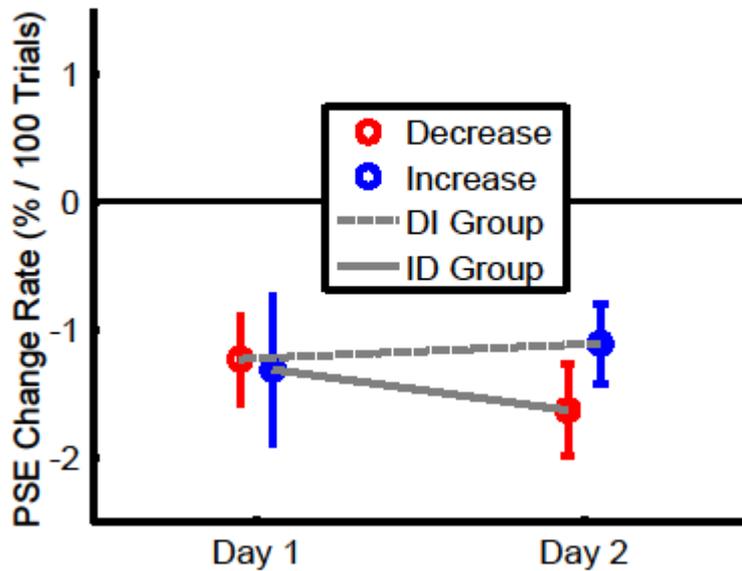


Figure 3. PSE change rates in the reverse re-calibration experiment. No clear evidence of reverse re-calibration was observed. Notice that since the Increase and Decrease labels refer to a change between foveal and peripheral vision, the expected PSE change would have been the opposite of the one observed in the main experiment (Figure 1E).

Stimulus motion experiment: re-calibration without saccades.

We execute saccades several times per second, and therefore saccades are presumably the main cause of association between peripheral and foveal targets. They are, however, not the only potential cause. Object motion can cause such associations whenever an object moves from the visual periphery into the fovea, or vice versa.

A further set of 16 observers was tested in a variation of the paradigm in which, after the usual size judgment, the observers did not execute a saccade, but the peripheral stimulus moved to the fixated location (Figure 4A, Supplemental Experimental Procedures).

The results show that the stimulus size change occurring during its motion towards the fovea did also produce some re-calibration of perceived size. In particular, the relative value of the PSE rate of change between the groups reverses between Day 1 and Day 2, according to the reversal of the size manipulation. Notice the similar pattern in Figure 4 and in Figure 2. This was confirmed by a 2-way ANOVA with Day (1 vs. 2) and Group (*IncDec* vs. *DecInc*) as factors, in which the 2-way interaction was significant ($F(1,14)=11.566, p<.004$), whereas the main effects of Day and Group were not significant (both $ps>.5$). Contrary to what we observed in the main experiment, the observers in the *DecInc* group did not show a lower PSE as testing began on Day 2 compared to the *IncDec* group ($t(14)=-.323, p=.751$), possibly indicating that the re-calibration induced without saccades is less stable. Similar to what we had observed in the main experiment, the overall PSE change seems smaller when the observers were exposed to a size increase. This is most likely due to a general bias to report peripheral objects as being smaller [e.g. 4].

Overall, our results indicate that the visual system continuously keeps size calibrated across the visual field. The phenomenon complements another learning phenomena, saccadic adaptation[20], where a trans-saccadic change in position leads to subsequent adjustments in the saccade metrics. This allows the oculomotor system to adapt to fluctuations and changes in the activity of the minutely controlled eye muscles. The specifics differ for saccadic adaptation, which is limited to the motor output and does not lead to a re-calibration of perceived position[21]. Furthermore, it is directionally specific [22, 23], whereas the trans-saccadic re-calibration of size is not bound to the saccade target location. However, both processes together, re-calibration at the motor and sensory side of the action-perception-loop, make sure that we always perceive the most adequate peripheral image and are able to act on it in the proper way.

While our results are largely consistent with the idea that sensorimotor contingencies maintain perceptual uniformity throughout the visual field[1, 3, 5, 6, 24, 25], they notably generalize this notion. We observed re-calibration even if the feedback about the prediction is provided in the absence of eye movements, indicating that predictions based on multiple sources of feedback about the relative appearance of stimuli in central and peripheral viewing are taken into account for re-calibration. While predicting the consequences of our actions is a fundamental aspect of motor control [26-28], predictive mechanisms have a much more widespread role in both perception and cognition. Arguably, perceiving the world can be seen as the construction of an internal model to predict changes in sensory stimulation due to internally triggered and externally determined events [29-32]. Our results show that prediction errors related to external events are indeed able to modify our perceptual system. The role of trans-saccadic prediction is still fundamental for perceptual re-calibration, since in our everyday life the most likely reason why a stimulus would end up in central viewing after having been viewed peripherally is that we executed a saccadic eye movement towards it.

We have shown that a continuous process of re-calibration, based mainly on the sensory consequences of our motor actions, underlies our subjective impression of uniformity throughout the visual field. Many objects in the world lead to peripheral images on the retina that cannot be distinguished – so called metamers[33]. We propose that prediction selects the most likely real-world object as our percept, rather than something based on the impoverished eccentric retinal images. Thus, objects in our peripheral visual field do not appear distorted or blurred [34] because our visual system learned to predict a given peripheral visual signal from the corresponding foveal signal. The learning of those peripheral-foveal contingencies is a continuous process that keeps fine-tuning our perceptual system throughout the life-span.

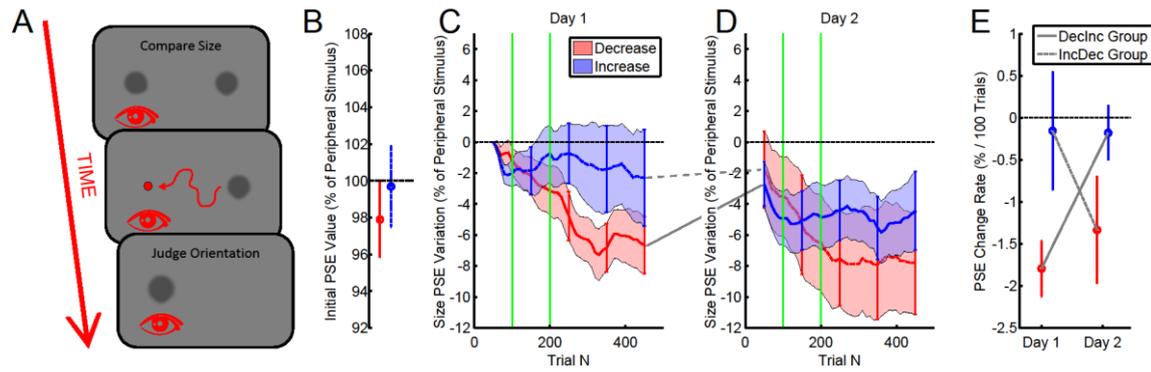


Figure 4. Procedure and perceived size modulation in the stimulus motion experiment. All conventions as in Figure 1. The procedure is identical to the one of the main experiment, except that the observers do not shift gaze and the stimulus moves towards the fixation point instead. As evidenced by the interaction in E, the PSE change rate is affected by the size change that took place during the movement, notice the similarity with the pattern in Figure 1E. The re-calibration taking place on Day 1 however does not seem to affect the initial value at the beginning of the testing on Day 2 (D).

Experimental Procedures

Each trial in our main paradigm started with the observers viewing one stimulus in the fovea and one stimulus 20° in the periphery, whose radii varied between trials (Figure 1A, Supplemental Experimental Procedures). The observer was asked to first compare the size of the two stimuli and then to look to the other stimulus and indicate the direction of its protrusion. During the eye movement, depending on the conditions and unnoticed to most observers, the radius of the target stimulus could increase or decrease by up to 10%. A detailed description of the other experiments is available in the Supplemental Experimental Procedures. Psychometric curves were fit to the size comparison responses over partially overlapping intervals of 100 trials, so as to chart the evolution of perceived size, i.e. the Points of Subjective Equality, over the course of the experiment.

Acknowledgments

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Supplemental Experimental Procedures

Participants

Forty observers took part in the main experiment. Sixteen observers were assigned to the *IncDec* and to the *Declnc* group, respectively, and eight observers were tested in the *Unchanged* condition. All of the observers in the *Unchanged* condition and half of the observers in each of the *Increase* and *Decrease* groups underwent post sessions without eye movements.

Sixteen observers took part in the reverse re-calibration experiment and another group of sixteen observers took part in the stimulus motion experiment, in both cases eight observers were assigned to the *IncDec* and *Declnc* groups, respectively. None of the overall 72 participants took part in more than one experiment. Participants in the study provided written informed consent in agreement with the Declaration of Helsinki. Methods and procedures were approved by the local ethics committee LEK FB06 at Giessen University (proposal number 2009-0008)

Stimuli

In the main experiment stimuli were two approximately circular gray (8.79 cd/m^2) patches presented over a lighter gray (25.55 cd/m^2) background (see Figure 1). Stimuli were presented on a 22-inch Eizo CG223W 10-bit LCD monitor (Eizo Corporation, Hakusan, JP), viewing distance was 40 cm. One of the stimuli was viewed foveally at the beginning of the trial, and its radius could be 1.54° , 1.62° or 1.7° on different trials. The radius of the peripheral stimulus, presented centered 20° right or left of the foveal stimulus, was determined adaptively for each observer and condition. Rather than being sharp, the border of the stimulus was defined by a cumulative Gaussian gradient with $\sigma=.2^\circ$. The stimuli had one protrusion with a Gaussian profile as a function of angle ($\text{std}=17^\circ$). The amplitude of the protrusion was determined for each observer in an adaptive fashion so as to produce 62.5% accuracy in a 4AFC task. The protrusion amplitude was on average smaller than $.05^\circ$, meaning that on most trials the stimuli were almost circular and despite the peripheral preview looking at the stimulus centrally was required to perform the orientation task. The protrusion in the peripheral stimulus pointed either up, down, right or left, and its orientation did not change trans-saccadically, whereas the foveal stimulus was randomly oriented.

The size of the peripheral stimulus was chosen in each trial following an adaptive procedure. Using adaptive stimulus placement procedures offers several advantages over the method of constant stimuli. Besides being in general more efficient adaptive methods are less susceptible to range effects, which tend to constrain the PSE values reducing the extent to which perceptual biases can be observed. Our procedure involved fitting a psychometric curve with a cumulative Gaussian model to the data from the last 100 trials obtained within the same condition and with the same central stimulus radius. The next value was then randomly generated from a Gaussian distribution with the parameters μ and σ as obtained from the fitting. At the beginning of each experimental session the procedure was initialized with a set of data from 100 simulated trials which we constructed so as to be fit with $\mu=1.62^\circ$ and $\sigma=0.37^\circ$ which were then gradually substituted with the trials provided by the observer. A similar procedure was used in order to select the amplitude of the protrusion in the stimulus on which orientation judgments were based. In this case the trial matrix was initialized with 40 trials at 25% accuracy and amplitude 0° and 50 correct trials with amplitude 0.41° .

The stimuli we used were exactly the same in the stimulus motion experiment. In the reverse re-calibration experiment the stimuli were perfectly circular except for the 16 ms interval when the oriented protrusion was presented.

Procedure and Eye Movement Recording

Main experiment

At the beginning of each trial the observers were required to fixate a small black dot either 10° right or left of the center of the screen if the observers did not undergo the post-session without eye movements or in the center of the screen if no post-session was conducted. Gaze position was monitored online throughout the trial at 500 Hz with an Eyelink II system (SR Research, Mississauga, Canada). If gaze was detected within 1.5° of the required fixation position, both the foveal and the peripheral stimulus appeared and the observer was required to report through a keypress which of the two appeared larger. If the observer broke fixation the stimuli disappeared and the dot indicating the required fixation position was shown. The observer was also allowed to trigger a drift-correction or a full re-calibration if the stimuli failed to appear. After the size comparison response, if an eye movement was required, the observers were allowed to gaze directly at the stimulus which was previously seen in the peripheral visual field. Both stimuli disappeared as gaze left the 1.5° tolerance window and only the previously peripheral stimulus was re-presented after a 50 ms gap when gaze was detected within 3° of its center. If the stimuli failed to appear because of substantial mis-calibration the observer was allowed to look back to the original fixation point, start a drift-correction or a new calibration and subsequently execute the saccade. The trial could only be completed if the observer experienced the trans-saccadic change. Pilot results indicated that the presence of the gap reduced the likelihood that the change in size was noticed by the observers. At this point the observers were required to press one of the four arrows to indicate the orientation and the experiment continued with the next trial. The orientation judgment was introduced in order to ensure that the observers would attend the stimulus also in the post-saccadic phase, since it appears that unattended stimuli are less likely to produce implicit learning [1]. Where appropriate (see below) the size of the previously peripheral stimulus changed as it re-appeared. Specifically, its diameter could either increase or decrease by up to 10%.

All observers underwent at least one session composed of 500 trials in which the eye movement always took place in the same direction. In the *Declnc* and *IncDec* groups, after the first 100 trials in which the size of the peripheral stimulus did not change, the change was ramped up linearly to the full extent of $\pm 10\%$ for another 100 trials and it remained at full extent for the last 300 trials. No size change took place for the *Unchanged* group.

Half of the observers in the *Declnc* and *IncDec* groups and all of the observers in the *Unchanged* group also underwent a post-session of 200 trials in which no eye movements were required and the orientation judgment was not provided. During this session the peripheral stimulus appeared alternatively on the right and on the left side of fixation. The combined sessions lasted between 75 and 120 minutes depending on the observer's reaction times.

The observers in the *Declnc* and *IncDec* groups repeated the same procedure on the following day. They were required to move their eyes in the same direction as they had on the first day, but the size manipulation was reversed, so that, after the 100th trial, the observers in the *Declnc* group experienced an increase of up to 10% in the size of the peripheral stimulus, whereas the observers in the *IncDec* group experienced a decrease of the peripheral stimulus size.

Our approach to the management of eye-tracking during the experiments was aimed mostly at making the sequence of the experimental trials as smooth as possible, ensuring that all observers were exposed to the same number of trans-saccadic changes and provided the same number of judgments in each session, so that the PSE values can be aligned in a meaningful way in Figures 1 and 4. One crucial advantage of our paradigm over the ones used by Cox and colleagues [2] and Herwig and colleagues [3], is that the perceptual judgment took place before the saccade was executed rather than across-saccades making a trial-wise selection based on saccadic parameters unnecessary.

Reverse re-calibration experiment

The procedure was identical to the one of the main experiment until the point when the observers directed gaze to the peripheral stimulus. Contrary to what happened in the main experiment, after the 50 ms trans-saccadic gap the stimulus at the saccadic target was swapped for a small red fixation dot, whereas the other stimulus re-appeared in the same position, now peripheral, with its size possibly changed according to the experimental condition. Between 50 and 1050 ms following the re-appearance of the now peripheral stimulus, its shape changed for one frame (16 ms) to an oriented shape similar to the ones used in the other experiments. Observers were informed that this change could only occur in this time frame, so that if they had not perceived any change relatively soon after stimulus onset they were supposed to guess its orientation. Given that preliminary data suggested that the oriented stimulus might be less visible if presented just after the saccade, four separate staircases determined the amplitude of the oriented protrusion based on the oriented stimulus onset delay (50-300, 300-550, 550-800 und 800-1050 ms).

Stimulus motion experiment

The procedure in the stimulus motion experiment was identical to the one of the main experiment until the point where the observers provided the size comparison judgment (Figure 4A). At this point the stimulus at fixation was substituted with a fixation dot and after 500 ms the formerly peripheral stimulus moved towards it. The motion path was chosen randomly from a sample of 71 scribble-like tracks. The tracks had been produced by one of the authors (MV) on a large touch-screen (Display++ LCD Monitor, Cambridge Research Systems Ltd, Rochester, UK). The digitized tracks were smoothed, scaled and re-aligned to cover the 20° distance between the peripheral location and the fixation point. The motion speed was also scaled so that the duration of the motion track was mapped to 2 seconds. If required by the experimental condition, between the 11th and the 90th frame of the motion path, i.e. between 166 and 1500 ms after motion onset, the size of the moving stimulus changed linearly from its original size to the size designated for foveal viewing.

We chose this method because re-playing the retinotopic stimulation would have generated the impression that the peripheral stimulus disappeared while the foveal stimulus grew or shrank. Furthermore having the stimulus move along the scribble path produced a strong impression of object continuity which might have been lost had we first erased the foveal stimulus and directly moved the peripheral stimulus to the fovea in one step.

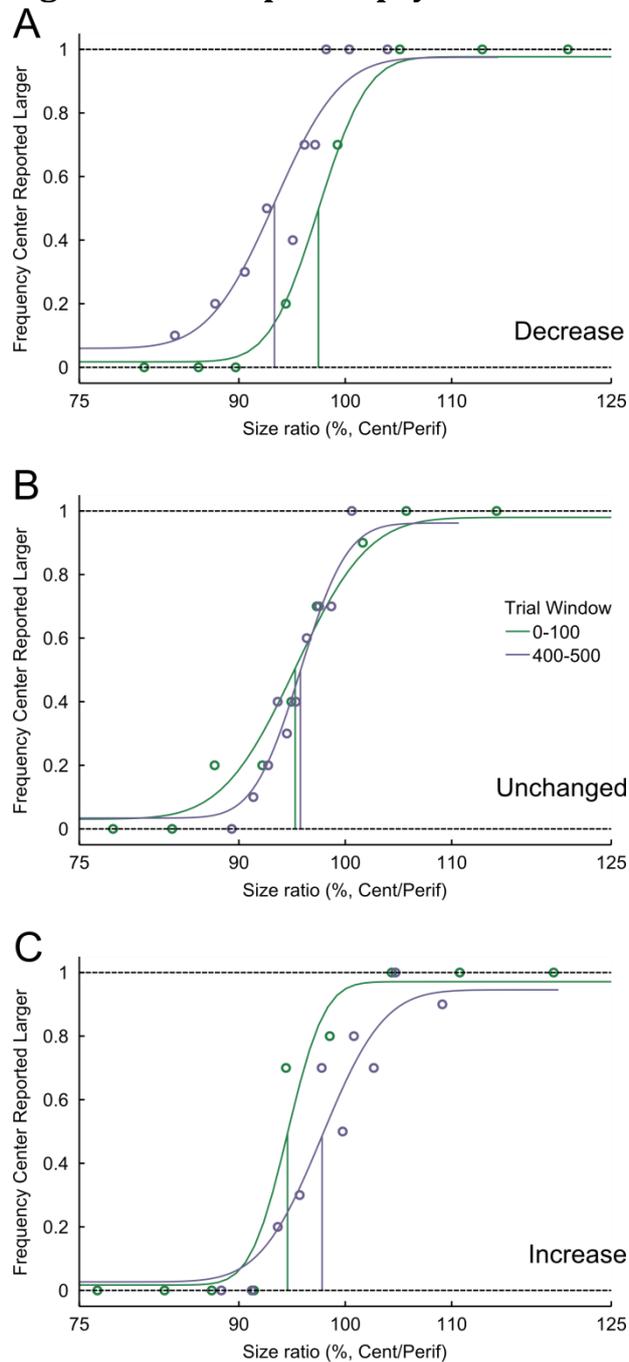
Observers were instructed not to look at the moving stimulus and to keep fixating the same location until the end of the movement. If gaze position was not located within 1.5° from the instructed

fixation location, the peripheral stimulus disappeared. Once the stimulus reached the fixation point, the observers were required to report its orientation.

Size manipulation awareness

All of the observers, except for those in the *Unchanged* group of the main experiment, were asked at the end of the testing on Day 2 whether they had noticed the experimental manipulation. In particular we first asked them if they had noticed any change in the stimulus. If they reported not noticing any change or noticing any change other than a variation in size, we specifically asked whether they had noticed any increase or decrease in the size of the stimulus towards which the eye movement was directed. The change in size was noticed only by a minority of the observers (23.4% overall, 8/32 in the main experiment, 3/16 in the reverse re-calibration experiment and 4 /16 in the stimulus motion experiment) and the overall pattern of results did not change if the corresponding data were not included in the analyses.

Figure S1: examples of psychometric curves



Example psychometric curves from the three size manipulation conditions (A: Decrease, B: Unchanged, C: Increase) obtained at the beginning (Trials 0-100) and at the end (Trials 400-500) of a training session in the main experiment. Vertical lines indicate the PSE values. According to the experimental manipulation, over the course of the session the PSE value increased in A, was relatively stable in B and increased in C. Data in A and C were obtained from the same observer on subsequent days. Notice that the PSE value in the trials 1-100 is lower in C compared to A, consistent with the lingering effect of the size decrease manipulation on Day 1. In all experiments we discarded from the analyses all data relative to psychometric curves where the standard deviation values exceeded .15.

This amounted to 1.7 % of fits in the main experiment, 0 % in the post-session, 0.5 % in the reverse re-calibration experiment and 0.3 % in stimulus motion experiment. Where possible, the missing

points were linearly interpolated for the purpose of plotting in Figure 2 and Figure 4. None of this affected the statistical significance of any of the results.

Supplemental References

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