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Spatial aspects of object formation revealed by a new illusion, shine-through

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Abstract

When a vernier stimulus is presented for a short time and followed by a grating comprising five *straight* lines, the vernier remains invisible but may bequeath its offset to the grating (feature inheritance). For more than seven grating elements, the vernier is rendered visible as a *shine-through* element. However, shine-through depends strongly on the spatio-temporal layout of the grating. Here, we show that spatially *in*homogeneous gratings diminish shine-through and vernier discrimination. Even subtle deviations, in the range of a few minutes of arc, matter. However, longer presentation times of the vernier regenerate shine-through. Feature inheritance and shine-through may become a useful tool in investigating such different topics as time course of information processing, feature binding, attention, and masking. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In a recent publication, we have shown that a preceding element can bequeath its features to a subsequently presented grating not possessing these features (Herzog & Koch, 2001). In the experiments, we presented an offset vernier stimulus followed immediately by a grating comprising *five* lines without vernier offset. Contrary to the physics of the stimulus, subjects perceived all elements of the grating as offset. We called this kind of backward masking feature inheritance. If asked on which of the elements observers based their discrimination between offsets to the right versus to the left, subjects reported to have paid attention to only one of the *outer* grating elements — while the foregoing vernier was presented at the *middle* of the grating. Using objective measures, we could show that this claim is justified. Therefore, features of the preceding vernier have to 'travel' from the center of presentation into the focus of attention, i.e. to the edge subjects attend to. Moreover, features of the grating displayed outside the focus of attention change observers' performance only marginally. For example, performance does not deteriorate significantly if the non-attended edge of the grating carries an offset that is always in the direction opposite to that of the preceding vernier. The same holds if the central element of the grating element carries an offset always in the direction opposite to that of the vernier: there is almost no change of performance. Not only vernier offset, but further properties such as the tilt of a single line or apparent motion, can be bequeathed to a grating (Herzog & Koch, 2001).

Feature inheritance occurs with gratings consisting of a *small* number of elements. Surprisingly, perception changes qualitatively if the grating comprises more than seven elements: the vernier becomes visible as a single element appearing wider, brighter, even longer, and superimposed onto the grating. Two independent entities are perceived: the vernier shining through and the grating without offset (Herzog & Koch, 2001). Performance in the shine-through condition is much superior to that in the feature inheritance condition, leading to far lower vernier discrimination thresholds. This shine-through depends in very subtle ways on the spatio-temporal parameters of the grating. In this report, we will focus mainly on the spatial parameters. In a companion

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paper (see this issue Herzog, Koch, & Fahle, 2001), we will present data on temporal aspects of shine-through.

2. General materials and methods

2.1. General set-up

Stimuli were displayed on an analog monitor (either Tektronix 608 or HP 1334 A), controlled by a Power Macintosh computer via fast 16 bit D/A converters (1 MHz pixel rate). In the experiments, a vertical vernier preceded a grating comprising a variable number of vertical verniers without offset. The horizontal distance between elements of the grating was between 200″ and 250″. In all quantitative experiments, the smaller spacing was used. Vernier segments are 600″ long and separated by a vertical gap of 60″ (see Fig. 1). So, the total vernier and grating element length was 1260″, and the width was around 30″. The vernier and the central element of the grating appeared always in the middle of the screen. The grating lasted for 300 ms and followed immediately after the vernier, i.e. without ISI (inter-stimulus-interval).

Subjects observed the stimuli from a distance of 2 or else 1.2 m in a room illuminated dimly by a background light (around 0.5 lx). The luminance of the stimuli was approximately 80 cd/m^2. Before stimulus presentation proper, a fixation dot appeared in the middle of the screen and four markers at the corners of the analog monitor. The refresh time was 10 ms.

2.2. Observers

Most quantitative data were obtained from paid undergraduate or graduate students from Caltech, USA, or the University of Bremen, Germany (mean age: about 23 years). Moreover, a technician from the section of human neurobiology in Bremen, a visiting professor, and the first author contributed data to the experiments (mean age: about 45 years). It seems that presentation times of the foregoing element have to be longer for older observers than for younger subjects to obtain comparable performances.

All observers had normal or corrected-to-normal visual acuity. Each observer was informed on the general purpose of the experiment. Some of the subjects had participated in experiments investigating feature inheritance before. Some observers participated in more than one experiment on the shine-through effect. Subjects were told that they could quit the experiment at any time they wished. Observers signed a consent form and had their visual acuity determined by means of the Freiburger acuity test (Bach, 1995). To participate in the experiments, subjects had to reach a value of 1.0 (corresponding to 20/20) in this test at least for one eye.

Before the experiment proper took place, we tested whether observers were able to perceive the vernier as a shine-through element by asking them to prepare line drawings and to give verbal descriptions of their percepts.

Most observers spontaneously perceived shine-through, whereas others did not. All subjects were familiarized with shine-through by short blocks (less than 10 trials) with vernier display times successively decreasing. If not otherwise stated subjects were trained in all experiments until they reached a stable level of performance. Special emphasis was given to reduce the presentation time of the preceding vernier. In all experiments, with the exception of the basic experiment in which naïve, untrained observers participated, presentation times of the vernier target ranged from 10 to 40 ms.

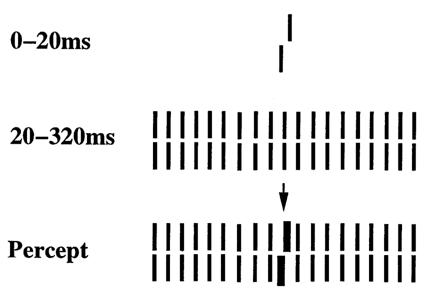

Fig. 1. Shine-through. A vernier is presented for a very short time and followed by a grating comprising more than seven elements. The foregoing vernier appears to be superimposed onto the grating and looks wider, brighter and, for some observers, even longer (see Herzog & Koch, 2001).

2.3. Task

Observers had to discriminate, in a binary forced choice task, the direction of the vernier shining through the grating by pressing one of two push buttons. A tone produced by the computer followed incorrect responses.

2.4. Strategies

We determined performance by measuring percentages of correct responses or by finding a threshold value via an adaptive staircase procedure (PEST; Taylor & Creelman, 1967). Percentages of correct responses were used as a measure in testing feature inheritance because in this case, adaptive procedures often yield unreliable results. If possible, we estimated thresholds instead of percentages of correct responses in order to be able to record the large range of performance differences.

In many conditions, subjective visibility of the preceding vernier is completely abolished. Adaptive strategies cannot handle these conditions properly because they present increasingly larger offsets trying to find the (non-existent) threshold, defined as 75% correct responses. Therefore, we prevented the PEST procedure from offering any offset size of the foregoing vernier exceeding 300″ [that is 1.5 times the width of spacing of 200″ between grating elements]. If observers were unable to reach a threshold value, an offset of 889″ was defined as 'in-discriminability' if, firstly, subjects' performance deteriorated with offset size in a monotonical fashion; secondly, an offset value of 300″ was offered by PEST at least once; and, thirdly, the hit rate for this value was below the threshold value. In ambiguous cases, the tested block was repeated. With 'visibility', we refer to *subjective* reports by observers about the existence of the foregoing vernier (perceived as shine-through element), i.e. we do not claim that the sensitivity index, d', would be zero in a 2-AFC task discriminating existence vs. non-existence of the preceding vernier.

Unless stated otherwise, for every subject, every condition was measured twice. The order of conditions was randomized individually for every observer to reduce possible hysteresis or order effects. After every condition had been measured once, the order of conditions was reversed for the second round of measurements in order to, at least partly, level out possible learning effects.

A block contained 80 stimulus presentations. Sessions contained no more than 20 blocks and usually lasted for 1–1.5 h but never exceeded 2 h.

2.5. Terminology

For gratings comprising more than five elements, it is convenient to call the central five elements the kernel. Elements not belonging to the kernel are called the context. In most conditions, the context consisted of nine or 10 elements displayed both to the left and right of the kernel. The conditions that present 5, 23, or 25 grating elements, all having the same parameters, are called the standard conditions.

3. Results

3.1. The basic effect

In the first condition, the vernier preceded, for a presentation time determined individually for each observer, a grating comprising five elements. Subjects were not informed about the existence of the foregoing vernier. They looked to their preferred edge of the grating and performed a vernier discrimination task as described in Section 1. Afterwards, they were introduced to shine-through. Six observers naïve regarding the aim of the study participated in this experiment.

3.1.1. Methods

Subjects were told initially that they would see a grating, comprising five elements, offset either to the left or to the right. Observers did not know that the offsets perceived were illusory, i.e. induced by a vernier preceding the grating. As is most often the case with feature inheritance, subjects looked spontaneously to one of the outer elements. Four observers preferred the left, one preferred the right edge. The remaining subject focused attention alternatingly on both edges during the experiment while keeping the focus of attention constant during each single presentation.

For each subject, the appropriate presentation time and offset size of the vernier were determined individually. We aimed to find parameters as quickly as possible in order to avoid learning effects or to familiarize observers with the feature inheritance condition. After performing the experiment on feature inheritance with gratings of five elements, a grating comprising 25 elements was presented. About half of the subjects continued to look to their preferred edge as in the condition before, and the other half recognized the preceding vernier as a shine-through element: looking brighter, wider, even longer than the grating elements and appearing as a flash superimposed on the middle of the grating (though parameters of vernier and grating elements were absolutely the same apart from the horizontal vernier offset). Subjects who continued to look to their preferred edge did not perform very well. They then received the hint to look at the center of the grating. In both cases (hint or no hint), observers were asked to discriminate offset direction of the shine-through element after a few training trials (less than 20). After this condition, subjects performed a control with the five element grating. They were free to base their decision on any cue they preferred, i.e. we neither restricted them to look to their preferred edge nor asked them to look at the center of the grating. In order to accommodate the large inter-individual differences, the adaptive strategy PEST determined vernier offset size to avoid floor and ceiling effects. Each of the three conditions was measured only for one block in order to prevent familiarizing observers with one of the conditions. The presentation times of the vernier ranged from 30 to 80 ms with a mean of about 51 ms.

3.1.2. Results

As Fig. 2 shows, performance is significantly superior in the '25-element' condition (46″, standard error: 5.88″) than in the 'five-element' conditions yielding values of 143″, standard error: 5.52″ (first condition), and 124″, standard error 6.14″ (second condition).

Subjectively, in the 'five-element' conditions, the vernier is not visible at all for most subjects, even though its offset can be discriminated. In the '25-element' condition, all observers perceive shine-through.

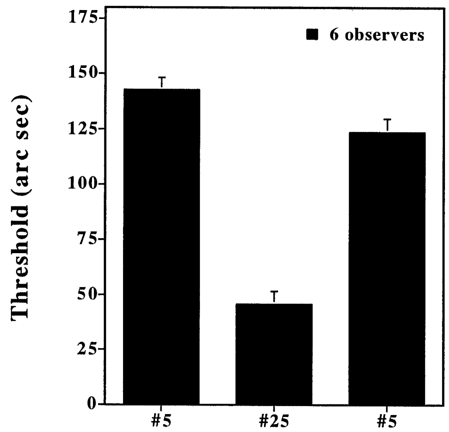

Fig. 2. Six observers participated in this experiment. They were naïve to the purpose of the experiment and were asked to discriminate the induced offsets of a five-element grating (left ‘ # 5’ element condition). Four observers looked to the left, one subject to the right edge, and the remaining observer switched attention between the left and right edge. Average thresholds are 363 cm (143 inches). After performing feature inheritance, observers were immediately introduced to the shine-through effect. For this condition, on average, a value of 117 cm (46 inches) is obtained significantly better than the mean of the preceding condition (paired t-test: $P = 0.003$). Finally, the first condition was measured again [right ‘ # 5’ element condition: 315 cm (124 inches) mean threshold]. This condition employs the same parameters as the first ‘ # 5’ element condition, but observers now did know about the preceding element. Still, a strong and significant difference exists compared to the condition with the grating comprising 25 elements (paired t-test: $P = 0.006$).

Line drawings show a vernier element superimposed onto the grating. If asked to describe their percepts, every observer used words like: brighter, wider, longer, flash(ed), or superimposed.

3.2. From feature inheritance to shine-through

As mentioned above, for five or less grating elements, no shine-through occurs, i.e. subjects experience feature inheritance and perceive a vernier offset at one of the outer elements of the grating. The vernier itself remains invisible. Hence, partially conflicting information (straight vs. offset) from within a small spatio-temporal window is bound together into one single object. However, the last experiment showed that 25 elements lead to shine-through. In this case, two ‘objects’ are perceived, and features of the vernier are not bound to the grating. In order to study the transition between these two states of *feature binding*, the number of elements of the grating was varied.

3.2.1. Methods

Three observers participated. All of them were well-trained subjects and familiar with both shine-through and feature inheritance. Two subjects preferred the left edge, one the right edge. Performance was determined in percentage of correct responses. However, because of large differences of performance between feature inheritance and shine-through, ceiling effects in the case of shine-through were unavoidable.

Two presentation times were used. One was the minimal time for shine-through to occur (20 ms for all subjects), and the other was the minimal time for feature inheritance (30 or 40 ms for different individuals). Observers were free to use any cue they wished, i.e. we asked them to look at neither the center nor one of the edges of the grating in any particular condition. However, we told our subjects that they could base their decision on the shine-through element as well as on the illusory offset perceived at one of the outer grating elements.

Subjects were also asked whether they experienced either shine through, hence whether they were looking at the middle of the grating, or feature inheritance, i.e. looking to their preferred edge.

3.2.2. Results

As Fig. 3 shows, performance is best for a ‘grating’ having only one single element and for gratings comprising more than 11 elements. If the grating had three or five elements, all observers reported to have experienced feature inheritance and in the conditions with more than seven elements all subjects based their decisions on the center of the grating (see Table 1). In the one-element condition, apparent motion was perceived. Performance and ‘looking’ strategy with gratings of seven and nine elements were highly different. If the grating comprised seven elements, one or two observers (depending on presentation time) focused on the center element. In the nine-element conditions, all observers based their decision on the center element. In this condition, only a faint shine-through element was often perceived, which did not look brighter and superimposed onto the grating. Still, an offset could be perceived, but performance usually decreased compared to ‘normal’ shine-through. Obviously, feature inheritance with gratings of more than one element yields performance inferior to conditions in which shine-through occurs.

A longer presentation time for the preceding vernier improves performance in both conditions.

3.2.3. Discussion

Feature inheritance and shine-through are not completely complementary effects. Inheritance occurs with gratings having a small number of elements, shine through requires more elements. In both cases, perception depends on the decision to which location to attend or fixate to. Shine-through and feature inheritance are only complementary in the sense that they occur with different, almost non-overlapping numbers of elements. With gratings of seven elements, some

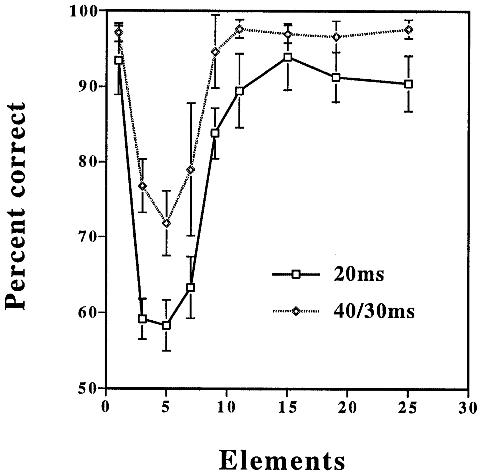

Fig. 3. Three observers, familiar with feature inheritance as well as with shine-through, participated in the experiment 2, varying the number of elements of the grating. Two observers preferred the left, and one subject the right edge of the grating under the conditions of feature inheritance. The number of elements was varied for two presentation times. The first condition (squares) used the shortest vernier display time at which subjects were able to perceive shine-through. This time was 20 ms for all three observers. The second condition (diamonds) employed the minimal vernier display time for feature inheritance to occur. This was 30 ms for two observers and 40 ms for the remaining one. Performance drops significantly from a presentation with a grating consisting of one to five elements but recovers with gratings of more than seven elements. Subjects experience feature inheritance or perform apparent motion discrimination with gratings of one to five elements and shine-through for gratings of nine and more elements (see Table 1). Conditions with seven elements yield ambiguous results. Parts of these data are presented in Herzog and Koch (2001).

observers are able to perceive both feature inheritance and shine-through with a superior performance in the last case.

3.3. Shine-through depends on the spatial layout of the grating

One straightforward explanation for shine-through is that it may occur because gratings with more elements allow a luminance increment to be detected at the center of the screen, while gratings with fewer elements do not. For example, the visual system might analyze a display by small (overlapping) patches and compare the energy of these patches with each other. A five-element grating with the spatial size used here might just not allow such comparisons because it cannot be covered by a sufficient number of (receptive field-like) patches. The result of the experiment varying the number of elements could, therefore, be caused by the sheer *number* of elements and its associated increase of *overall* energy.

In this experiment, we show that the spatial layout — and not the sheer number of elements itself — determines performance as well as perception.

3.3.1. Methods

The vernier was presented for 20, 30, or 40 ms (depending on observer) and followed immediately by the kernel, which always contained five straight elements. The center element of this array appeared at the location where the vernier had appeared before, i.e. in the middle of the screen. At the same time as the kernel, the context elements were presented with variable spatial properties: their distance to the kernel, their orientation, or their length differed.

In the ‘gap’ condition, the context was moved away from the kernel in horizontal direction, thus creating two gaps (see Fig. 4, top left). The gap width was two spacings between elements, corresponding to the omission of one grating element. In the ‘tilt’ conditions

Table 1
Table showing whether in experiment 2, depending on the number of elements making up the grating, observers experienced apparent motion (AP), feature inheritance (FI), or shine-through (shine)

Number of elements:	1	3	5	7	9	11	15	25
30/40 ms:								
Observer								
AR	AP	FI	FI	FI	Shine	Shine	Shine	Shine
MH	AP	FI	FI	Shine	Shine	Shine	Shine	Shine
KS	AP	FI	FI	Shine	Shine	Shine	Shine	Shine
20 ms:								
Observer								
AR	AP	FI	FI	FI	Shine	Shine	Shine	Shine
MH	AP	FI	FI	FI	Shine	Shine	Shine	Shine
KS	AP	FI	FI	Shine	Shine	Shine	Shine	Shine

Observers experience feature inheritance for gratings comprising three and five elements while shine-through for arrays with nine and more elements. A one-element ‘grating’ elicits a percept of apparent motion. MH experienced, in the conditions ‘seven elements, presentation time 30 ms’ and ‘nine elements, display time 20 ms’ only a faint shine-through percept. This observer collected information in the center of the grating, but the vernier did not look brighter and superimposed but very faint with an offset. The same holds for observer KS in the ‘20 ms, seven-element condition’.

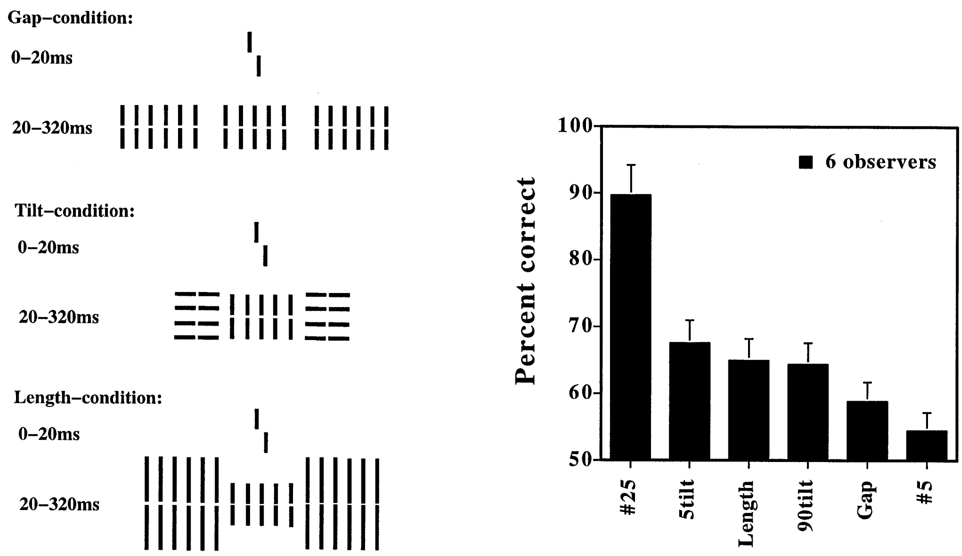

Fig. 4. Variations of the spatial layout of the grating: set-up and results (see also Fig. 4 in Herzog and Koch, 2001). In the 'gap' condition, context and kernel were separated by two clefts of a width of two spacings each (top left), i.e. each gap results from the omission of one grating element. In the 'tilt' conditions, context elements were tilted by 5 or 90 degrees to the left from the vertical (center left). In the 'length' condition, context segments were 120″ long, i.e. twice as long as the kernel segments having a length of 600″ (bottom left). Finally, performance in the standard 5 and 25 elements (# 5, # 25) conditions was determined. In the left part of the figure, element numbers of the gratings were reduced for improved clarity. Clearly, performance is best for the standard 25-element condition. Performance deteriorates with inhomogeneous gratings and the five-element array.

context elements were tilted by either 5 or 90 degrees from the vertical (Fig. 4, middle). If the elements were rotated around 90 degrees, the context comprised only two times five elements (Fig. 4 shows only four of them for graphical clarity). In the condition 'length', segments of the context elements were twice as long as segments of kernel elements, i.e. 1200″ instead of 600″ (see Fig. 4, bottom).

All observers were first introduced to the general paradigm of presenting a vernier followed by a grating and that the vernier might or might not shine through. A few practice trials were carried out for each of the above conditions (less than 10 trials) to make subjects feel comfortable with the change of conditions. The presentation time of the preceding vernier was 20 ms for four subjects, and 30 and 40 ms for the remaining two subjects.

We also asked observers about their subjective experiences: 'Did you perceive the preceding vernier as a shine-through?' Only binary responses (yes and no) were allowed and strictly enforced.

3.3.2. Results

As can be seen from Fig. 4, small variations of the spatial layout of the grating can yield a significant deterioration of performance compared to the standard condition of 25 homogeneous, equally spaced elements for which a ceiling performance is reached (ANOVA, Bonferroni–Dunn corrected post-hoc tests: $P \leq 0.0003$). Performance is worst if the grating comprises only five elements or contains gaps. A tilted context or longer context elements lead to better performance.

The differences in performance between these conditions correspond to perceptual visibility, as can be seen from Table 2. The better performance, the more subjects will report shine-through. No observer is able to perceive shine-through in the standard five-element condition (# 5) and in the 'gap' condition. All observers see the vernier shining through if the grating comprises 25 elements. For the 'length' and the 'tilt' conditions, the results are heterogeneous. One group of observers perceives shine-through, while the other does not. Subjective and objective results correspond very well. For each observer, we computed the mean performance in conditions in which shine-through was reported (84.8% correct responses) and those in which shine-through was not reported (57.1% correct responses) which differed significantly (paired t-test: $P = 0.0005$).

3.4. Gap width variation

This experiment gives a quantitative account of how performance changes with the layout of the grating. As an example, we used the 'gap' paradigm. The context was moved away from the kernel in horizontal direction creating a gap. The size of this gap was varied.

Table 2
Depending on the spatial layout, observers experienced shine-through (yes) or not (no) in experiment 3

Layout	# 25	5 degree tilt	Length	90 degree tilt	Gap	# 5
Observer						
JC	Yes	Yes	Yes	Yes	No	No
SM	Yes	Yes	Yes	Yes	No	No
KS	Yes	Yes	Yes	No	No	No
KY	Yes	No	No	No	No	No
AR	Yes	No	No	No	No	No
MH	Yes	No	No	No	No	No

In the case of a 'no' response, subjects did not perceive a shine-through element, but they may have experienced feature inheritance. All observers perceived shine-through for the standard 25-element condition, but none of them did so in the standard five-element condition or in the gap condition. Results are heterogeneous for the 'length' and 'tilt conditions. One group of observers perceived shine-through [JC, SM, KS (not 90 degree)], whereas the other did not (KY, AR, MH).

3.4.1. Methods

Stimuli had the same parameters as in the 'gap condition' of experiment 3. However, different gap sizes were used created by moving the context while keeping the number of elements constant. The kernel consisted of five elements and the context of nine elements on both sides, so altogether, 23 grating elements were displayed.

Spacing between elements was 200″ for all subjects. The values on the abscissa of Fig. 5 indicate the additional width of gaps beyond the standard spacing of 200″. For example, a value of 100″ means that the context is moved away from the kernel by an additional 100″ as compared to the standard spacing of 200″, i.e. the whole gap (element to element) is 300″ wide. We used this kind of labeling because the important parameter is not the absolute gap width but the difference in spacing. Thresholds were estimated via the adaptive staircase procedure. For three observers, the presentation time was 30 and 20 ms for the remaining subject.

In a second condition, thresholds were determined for a gap width of 100″, three presentation times of the vernier, and the same subjects as in the last experiment. We used the same display time, t, as before, which was approximately the minimal time for shine-through to occur, and presentation times of 10 ms longer $(t+10)$ and 10 ms shorter $(t-10)$ than this minimal time. We also determined performance with the standard grating using all three display times.

3.4.2. Results

With increasing gap-size performance deteriorates monotonically and almost linearly (see Fig. 5).

Performance depends on the presentation time of the preceding vernier. Changes in the range of only 10 ms difference from standard display time yield strong deterioration $(t-10)$ or improvement $(t+10)$ of performance (see Fig. 6). Therefore, not only the spatial but also the temporal layout of the grating plays an important role in shine-through conditions. It should be noted that different display times also have different stimulus energy (luminance*duration).

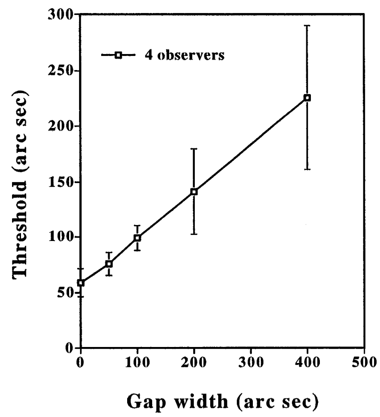

Fig. 5. Discrimination thresholds of four observers as a function of gap width (see Fig. 4, top left). With increasing gap size, performance decreases strongly and almost linearly. A width of 0 indicates the standard condition, while a gap size of 200″ corresponds to the 'gap' condition of experiment 3, i.e. the layout of the grating results from the omission of two elements (and adding these elements at the outer ends of the grating).

This result has a parallel in the subjective experiences. For a presentation time 10 ms shorter $(t-10)$ than the standard (t), shine-through completely disappeared for all but one subjects. However, if the vernier was presented 10 ms longer $(t+10)$ than the standard display time, all observers perceived shine through and performance differences vanished in the 'gap' as well as in the standard condition (see Fig. 6). Analogous results are obtained for most conditions of experiment 3 if presentation times are varied (results not shown here).

3.5. Gap filling

If the grating contains two gaps, shine-through diminishes, and performance deteriorates. In the present

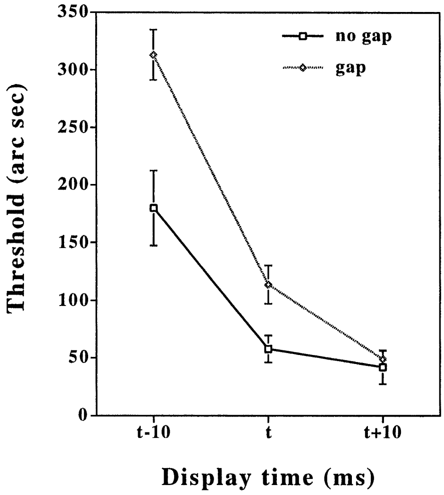

Fig. 6. The same four observers who participated in the last experiment joined this experiment testing the influence of presentation time of the preceding vernier on shine-through. In the first condition, the grating contained two gaps with a width of 100″ ('gap'). In the second condition, the grating did not contain any gaps at all ('no gap', i.e. the standard condition). For every observer, performance was tested with three presentation times: the display time used in the last experiment (t) and presentation times differing by ± 10 ms from t. Performance improves with display time under both conditions. However, with longer display times, the difference in performance between these two conditions vanishes, and shine-through is perceived by all subjects.

experiment, each gap contains an element whose length varies. In this sense, we fill the gap as a dentist fills a carious tooth.

3.5.1. Methods

The kernel consisted of five elements and the context of nine elements. Kernel and context were separated by two gaps of a width of 400″, i.e. corresponding to omitting one element. The two gaps were filled with two elements, respectively, of various length ranging from 1200″, i.e. maximally twice as long as in the standard condition (see Fig. 7, left).

3.5.2. Results

Performance varies in a U-shaped fashion if the length of gap elements changes, being best if the grating is homogeneous and deteriorating for longer and shorter elements (Fig. 7). Increasing the length of elements in the gaps compared to the standard length by only 150″ leads to a doubling of thresholds. Therefore, changes in the range of only a 24th of one degree of visual angle dramatically deteriorate performance.

Shine-through occurs in most conditions but is abolished for all subjects if the grating contains 'empty' gaps or the elements in the 'gaps' are double as long as the other elements of the array.

4. General discussion

4.1. Spatial aspects

For five- and three-element gratings, subjects look to one of the edges of the grating where they might perceive an illusory offset (see Table 1, Fig. 3, and

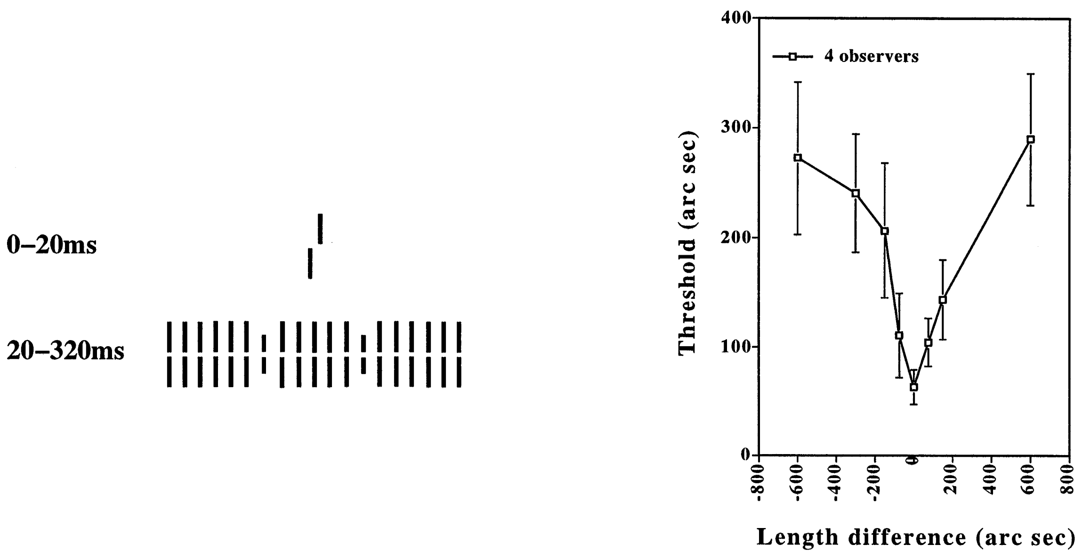

Fig. 7. For four observers, the length of elements filling the gaps was varied. The abscissa shows the difference in length of the segments of the gap filling elements compared with the standard segment length of 600″ (a vernier consists of two segments: one above and one below the small vertical gap). Hence, a difference in length of 0 arcsec indicates the standard condition, while a difference in length of -600″ corresponds to the 'gap' condition of experiment 4 (see Fig. 4 top left), i.e. an empty gap. At a difference of length of 600″, the 'gap fillers' are twice as long as the other grating elements. The performance curve is U-shaped. Clearly, performance is best if all grating elements have the same length (0 arcsec). Deviations from this length increase thresholds independent of whether 'gap fillers' are longer or shorter than the other grating elements.

Herzog & Koch, 2001). Longer presentation times lead to a better performance (see Fig. 3). Gratings with nine and more elements lead to shine-through. It should be mentioned that feature inheritance and shine-through depend on a mutually exclusive and voluntary decision on which of the grating elements, i.e. location, discrimination is based.

Shine-through depends in subtle ways on the spatial layout of the grating. For example, tilting the context around 5 degrees deteriorates performance. If context elements are rotated around 90 degrees, performance decreases even more strongly. These results are in contrast to many studies investigating the role of contextual surrounds on the firing rates of cortical neurons: orthogonal surrounds yield better results than iso-oriented ones (e.g. see Sillito, Grieve, Jones, Cudeiro, & Davis, 1995; Li, Thier, & Wehrhahn, 2000; cf. Polat & Sagi, 1994).

Spatial changes in the range of only a *24th* of one degree of visual angle can change performance dramatically, since performance deteriorates strongly if the length of elements in the gaps exceeds 150″. This sensitivity for stimulus parameters seems to be very high considering that the elements in the gaps are not part of the target but of the context. None of their 'direct' properties are important for the task of vernier discrimination. Moreover, the gaps are outside the focus of attention (see Herzog & Koch, 2001). It seems that a very precise homogeneity of the grating is important for shine-through.

4.2. Perception and performance

Shine-through can be perceived as a very salient event or else as a very faint impression. The strength of the illusion depends on the energy of the vernier (luminance*duration; see Fig. 6) and only to a very small extent, if at all, on the spatial offset of the vernier (see Herzog, Koch, & Fahle, in press).

Almost all observers are able to experience shine-through, and many discover shine-through, even without being instructed to see it. However, one out of about 50 observers was, even after extensive training, not able to perceive shine-through but performed feature inheritance very well.

In some conditions, observers experience 'strange percepts'. For example, for a context longer than the kernel, some subjects perceive a tilted line and base discrimination on the orientation of this element while the offset remains invisible. However, in this case performance is much worse than in 'usual' shine-through. For other subjects, the vernier is completely lost, i.e. suppressed in this condition.

As always with detection tasks without a physical zero, inter-individual differences in the decision criterion of whether or not perceiving shine-through may be high. However, shine-through seems to be a fairly consistent effect co-varying well with performance. Moreover, reports are consistent in the sense that no subject ever reported shine-through in a condition in which performance was worse compared to another one for which no shine-through was reported. For example, no subject reported shine-through in the 90 degree condition but not in the 5 degree condition (see Table 2).

Shine-through is an illusion in the sense that the vernier is not perceived as a single event *preceding* the grating. If this were the case, the vernier should also be visible with a grating containing gaps or comprising five elements. Moreover, shine-through is not caused by luminance fusion of the preceding vernier with the central grating element (see Herzog et al., in press).

4.3. Mechanisms leading to feature inheritance and shine-through

The results of experiment 3 show that shine-through cannot be explained by the sheer number of elements — and the associated increase in stimulus energy — since in the 'gap' and 'tilt' conditions, only the spatial layout differs from the standard grating, while the element number stays constant. Hence, energy is the same, while performance and perception change. Therefore, a faster processing of high-energy stimuli, as proposed, for example, to explain the effects of Pulfrich's pendulum, cannot account for our results.

So, why do feature inheritance and shine-through depend so strongly on the spatial layout of the grating? Image segmentation processes parse a stimulus into homogeneous parts of textures or objects. The key idea is that during segmentation, neural responses corresponding to the *edges* of a texture are strongly enhanced, while they are diminished if they are part of the object's interior. In the realm of luminance processing, analogous mechanisms are usually thought to be carried out by lateral inhibition. Contrast effects, analogously to Mach Bands, exist for spatial frequencies (MacKay, 1973; McCarter & Roehrs, 1976; Sagi & Hochstein, 1985). Moreover, Macknik, Martinez-Conde, and Haglund (2000) found edge enhancement in a masking study using electrophysiological recordings. We assume that excitation and inhibition between neurons are balanced. Neurons 'coding' edge elements receive inhibition from a smaller number of neurons than neurons corresponding to 'inner' grating elements. For a more detailed description of the suggested processes, see Herzog et al. (in press) and Eurich, Bormann, and Herzog (2001).

The strong neural responses elicited by the edges of a *small* grating interfere with the responses produced by the foregoing vernier and, therefore, its visibility is masked. However, vernier offset, which may be computed by neurons tuned to oblique orientations

(Wilson, 1986; Waugh, Levi, & Carney, 1993) is not completely masked and can, therefore, possibly be bequeathed to the small grating. If a homogeneous grating, however, comprises a sufficient number of elements, the edges of the grating are remote, and interference is weak. In this case, the preceding vernier induces its features to the illusory shine-through element at the same position of the following grating. In the 'gap condition', three arrays of elements are segmented, and the edges of the center grating, i.e. kernel, yield strong masking of the foregoing vernier. It should be mentioned that, different from lateral inhibition in luminance computation, the retina is an unlikely candidate as the main physiological location for the neural processes producing shine-through. Firstly, small differences in orientation between kernel and context matter, while the retina contains only concentric center surround receptive fields. Secondly, small spatial inhomogeneities of a 24th of a degree of visual angle influence performance (see Fig. 7). These effects occur with both luminance decrements (smaller 'gap fillers') and increments (larger 'gap fillers'), i.e. less and more energy in the receptive field. Again, ganglion cells with concentric receptive fields cannot detect these differences in the grating. Thirdly, as preliminary data show, the strong effects of spatial layout of the grating on the visibility of the vernier do not occur before a grating duration of 40 ms (Herzog & Fahle, 2001). This last result, in particular, favors re-entrant architectures, as proposed for other masking effects such as substitution masking (Enns & Di Lollo, 1997).

Performance differences between feature inheritance and shine-through may alternatively be explained by a 'distribution' of features. In shine-through, only one single illusory element inherits the offset, while in feature inheritance, properties are bequeathed to *five* elements.

4.4. Related findings

Banks and White (1984) reported that additional elements can improve perception of a stimulus, even if the 'kernel' is identical. If target letters were masked by other nearby letters, performance was better if the lateral elements could be grouped, and the masking effect decreased. For example, a single letter 'T' is more strongly masked by a neighboring single letter 'H' than by many letters 'H' of the same size grouped in a column. Similarly, Weisstein and Harris (1974) found better detection of a single line if this line belonged to an object appearing three-dimensional than when the line was an element of a pattern looking flat. Verghese and Stone (1997) showed that the spatial layout of stimuli affect speed discrimination. Spatially non-overlapping, collinear flankers can improve the detection of low contrast targets (e.g. Dresp, 1993; Polat & Sagi, 1993, 1994; Kapadia, Ito, Gilbert, & Westheimer, 1995; Wehrhahn & Dresp, 1998). Economou, Annan, and Gilchrist (1998) showed that simultaneous contrast depends on the context rather than on the background.

Li et al. (2000) found performance improved in a backward masking paradigm when mask size increased. Using letters 'T' and 'L' as target elements in a search task Scheier et al. (1999) showed that small 'patchy' masks following a target lead to weaker performance than a homogeneous mask covering the whole display. Ramachandran and Cobb (1995), modifying a demonstration by Werner (1935), showed that metacontrast decreases when masking objects are grouped. Perception of a disk surrounded by two squares and two additional disks was less vivid if observers grouped the 'outer' disks than if this disk was grouped with one of the 'outer' disks.

Feature inheritance was first reported by Werner (1935). He showed that a disk with spokes remains invisible if masked by a surrounding annulus while the annulus inherits the spokes. Wilson and Johnson (1985) showed that a gap of a line can be inherited by following unbroken line. Analogous results were found for the letter 'C' bequething the gap to a following annulus (Stewart & Purcell, 1970). However, these effects do not mis-locate spatial features, i.e. inheritance of properties occurs at the location of the carrier of the features. Feature inheritance is just one instance of paradigms showing that properties can be freed from their carriers. For more details on this and other topics, such as backward masking, please refer to the discussion of the companion publication in this issue (Herzog et al., 2001).

4.5. Summary

The complementarity between feature inheritance and shine-through may become a useful tool in the investigation of different research areas such as feature binding and attention, since performance, perception, focus of attention, and other aspects change after pure context changes with constant kernel.

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