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Shine-through: temporal aspects

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Abstract

If a vernier stimulus precedes a grating for a very short time, the vernier either remains invisible, but may bequeath some of its properties to the grating (feature inheritance), or might *shine through* keeping its features — depending on the number of grating elements [Herzog, M. H. & Koch, C., 2001. Seeing properities of an invisible element: feature inheritance and shine-through. Proceedings of the Natlional Academy of Science USA 98, 4271–4275]. Feature inheritance and shine-through represent two different states of feature binding [Herzog, M. H., Koch, C., & Fahle, M., Switching binding states. *Visual Cognition* (in press)], whereas shine-through depends in subtle ways on the *spatial* layout of the grating [Herzog, M. H., Fahle, M., & Koch, C., (2001). Spatial aspects of object formation revealed by a new illusion, shine-through. *Vision Research*]. Here, we show that also temporal parameters of the grating influence shine-through. For example, a delayed presentation of certain grating elements can deteriorate performance dramatically.

Keywords: Masking; Object segmentation; Shine-through effect; Temporal processing; Verniers

1. Introduction

For an introduction to feature inheritance and shine-through and the 'General Materials and Methods', please refer to the preceding publication by Herzog, Fahle, and Koch (2001). In short, a vernier stimulus presented briefly before a grating can be completely masked, perceived as a 'shine-through' element, or else bequeath its offset onto the grating, i.e. a grating comprising straight elements appears to be non-aligned (feature inheritance). The transition between these states depends on the number of grating elements as well as on the display time especially of the vernier. For every observer, we aimed to find the minimal presentation time of the vernier for which shine-through just occurred. This time was used in all the experiments (except experiment 1).

1.1. Terminology

The five central elements of the grating are called the kernel. Usually, on each side of the kernel, nine additional elements were presented; thus, the grating contained altogether 23 elements. We call these two times nine additional elements the context. In all conditions, the vernier and the center element of the grating appeared in the middle of the screen. The condition in which the grating comprises 23 homogeneous and simultaneously displayed elements will be called the standard condition.

2. Experiments

2.1. Timing of shine-through

It is often difficult to exactly determine the shortest display time of the preceding vernier for which shine-through just occurs. For most observers, differences of display time in the range of only a few milliseconds can change perception and performance dramatically, and the vernier will be completely masked for too short presentation times.

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2.1.1. Methods

The vernier was displayed for either 10 ms (V10) or 20 ms (V20) and followed immediately by the standard grating with standard duration of 300 ms. In a third condition, the vernier was presented for 20 ms and followed by the grating lasting for 1200 ms (G1200). Six observers participated.

In a second experiment, we presented the vernier for either 10 or 20 ms immediately followed by the grating or else by an inter-stimulus-interval (ISI) of 10 ms before the grating was presented. In a fourth condition, a vernier with doubled luminance was presented for 10 ms without ISI. Finally, verniers without following grating were displayed for 10 or 20 ms or else for 10 ms with doubled luminance. Four new subjects and the first author participated. For four subjects, the minimal time was shorter than 20 ms. In this experiment, we determined thresholds for vernier offset discrimination.

2.1.2. Results and discussion

As Fig. 1 shows, a difference in display time of only 10 ms leads to a dramatic change of performance. Most observers do not experience shine-through in the 10 ms condition, but with 20 ms presentation time, the vernier is clearly visible, yielding near perfect performance. However, two out of the six observers were able to perceive shine-through even with a display time of only 10 ms, but performance was not as good as in the 20 ms condition (mean difference for these two subjects: 19%). For a fixed vernier presentation time of 20 ms, a longer duration of the grating changes performance by only 1% if the grating lasts for 1200 ms instead of 300 ms. Differences of performance cannot be determined exactly because of ceiling effects in both conditions.

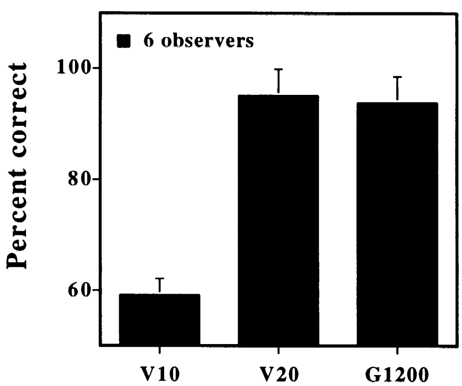

Fig. 1. The foregoing vernier was presented for either 10 or 20 ms (V10 and V20, respectively) and followed by a grating lasting for 300 ms. In a second condition, the vernier was presented for 20 ms, and the grating lasted for 1200 ms (G1200). A difference of vernier presentation time of only 10 ms reduces performance highly significantly from about 95% (V20) to 59% (V10) correct responses. Quite to the contrary, a longer presentation time of the grating seems to play a minor role (G1200). Performance is virtually identical for both grating presentation times employed (difference: 1%). Vertical bars indicate standard errors of the means.

In the second experiment, reducing presentation time to 10 ms yields a deterioration of thresholds by a factor of 2.6 compared to the 20 ms condition. Introducing an ISI of 10 ms improves performance (by a factor of 1.4) and so does a vernier with doubled luminance (factor 1.2). Clearly, the blank period, i.e. additional processing time, improves performance (paired t-test 10ms.0msISI vs. 10ms.10 msISI: $P = 0.0405$). This effect is even more pronounced if the minimal time and half the minimal time are used as presentation times (results not shown here). For the verniers without following grating, luminance and duration seem to be mutually exchangeable (Bloch's law). A doubling of vernier duration has almost the same effect as a doubling of presentation time.

2.2. Context onset variation

As shown in Herzog et al. (2001), shine-through occurs with gratings of nine and more but not with arrays of less than seven elements. Introducing gaps between kernel and context can deteriorate performance and even abolish shine-through, indicating a major role of the grating's spatial layout for shine-through. In this experiment, we show that also the temporal characteristics of the context are important for shine-through to occur.

2.2.1. Material and methods

For four out of five observers, the vernier was presented for 20 ms and immediately followed by a grating comprising five elements, i.e. the kernel. For the remaining observer, the vernier had to be presented for 30 ms and before, simultaneously with, or after the kernel the context was displayed, i.e. two times nine elements at each side of the kernel (see Figs. 2, 3A and 4). Note that for negative onset differences of − 10 and − 20 ms, context and vernier were presented at (partly) overlapping times. Spatial parameters of the context were the same as those of the kernel. Simultaneous presentation of context and kernel represents the standard condition. The task was to discriminate the offset of the shine-through element. If the vernier was invisible, observers had to guess. Subjects were asked whether or not they had perceived shine-through after a condition was finished. In Fig. 4, 'onset difference' means the temporal difference in onset between context and kernel (not the vernier). All grating elements disappeared at the same time, i.e. 300 ms after kernel onset.

We also determined performance for a grating comprising only five elements, i.e. the kernel.

2.2.2. Results and discussion

As Fig. 4 shows, results are best if kernel and context are presented at the same time or if the context pre-

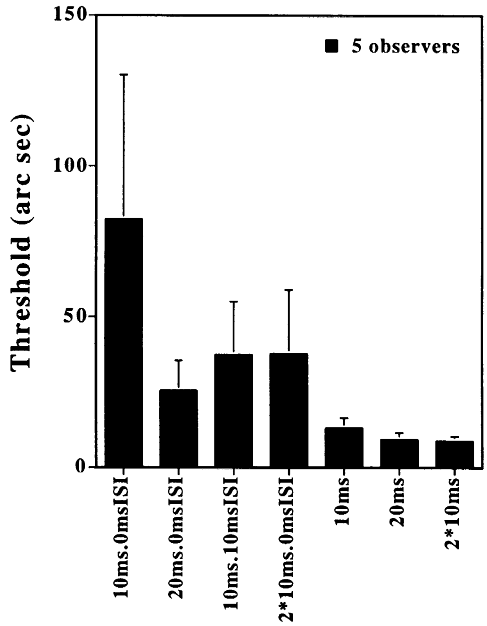

Fig. 2. In order to investigate whether the display time of the vernier per se or rather the energy, i.e. the product of luminance and duration, caused the better performance in the last experiment, we presented verniers under the following conditions. In the 10ms.0 msISI condition, the vernier was displayed for 10 ms and immediately followed by the grating comprising 23 elements and analogously in the 20ms.0 msISI condition. In the 10ms.10 msISI condition, the grating appeared after a blank period of 10 ms (ISI). In the 2*10ms.0 msISI condition, a vernier with doubled luminance was flashed before the grating appeared without ISI. As controls, we displayed verniers for 10 and 20 ms without following gratings and a vernier for 10 ms with doubled luminance (2*10 ms) without grating. As in Fig. 1, reducing vernier presentation time yields the lowest performance, while providing a 10 ms ISI or a doubled luminance vernier improves performance. Hence, additional processing time, i.e. a 10 ms ISI, clearly helps. A vernier, without following grating, presented for 10 ms leads to a lower performance than a vernier displayed for 20 ms, which yields a performance comparable to a vernier displayed for 10 ms having a doubled luminance.

cedes the kernel by 10 ms. The most surprising result is that even a delay of the context of only 10 ms relative

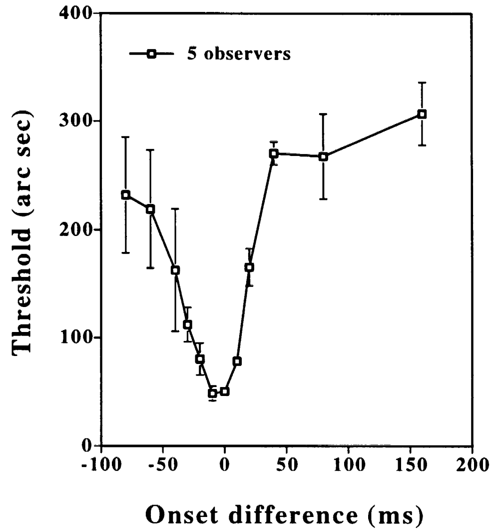

Fig. 4. The temporal onset of the context relative to the kernel was varied (abscissa). A value of 0 ms corresponds to a simultaneous presentation of all 23 elements of the grating. Negative values indicate that the context appeared before the kernel. The ordinate indicates threshold. Clearly, delays of the context deteriorate performance strongly. The same holds for a context displayed at least 20 ms before the kernel. The corresponding subjective impressions regarding shine-through are listed in Table 1. Some of the data of this figure are presented in Herzog and Koch (2001).

to the kernel increases thresholds significantly from 51″ to 79″ (paired t-test $P = 0.0016$). If asked after the experiment, none of the subjects had subjectively perceived a difference to the standard condition apart from diminished shine-through, i.e. observers were not aware of the delay of the context.

However, if the context appears 10 ms earlier than the kernel, performance is almost the same as with the simultaneous presentation (for the subject who saw the vernier for 30 ms, performance was constant if the context appeared 20 ms before the kernel, while it deteriorated strongly if vernier and context were presented simultaneously, i.e. at a 30 ms difference be-

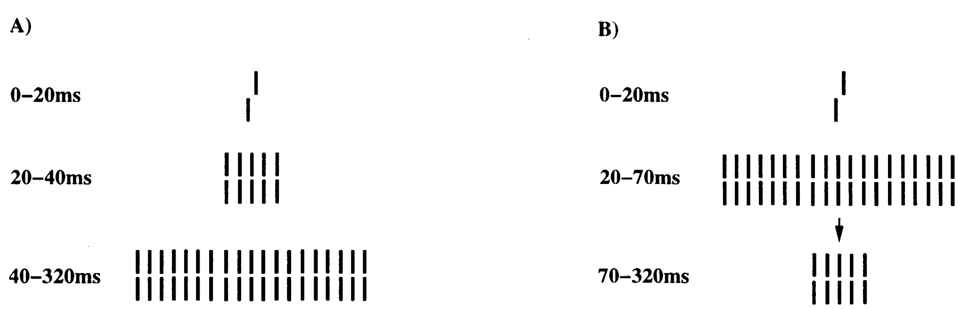

Fig. 3. Stimuli of experiment 2, with variable onset of the context, and experiment 3, with variable temporal offset of context. (A) In experiment 5, varying the temporal onset of context, a vernier is presented for a short time followed immediately by the kernel lasting for 300 ms. Before, simultaneously with, or after the kernel, the context is displayed (in this figure, the context is delayed by 20 ms relative to the kernel). (B) In the experiment varying the offset of context, the vernier is presented first, followed immediately by all 23 elements of the grating. The duration of context elements is varied (in the above example, they last for 50 ms). Not all 23 elements of the grating are shown in this and the following figures.

Table 1
In the experiment varying the onset of context elements, subjects were asked to report whether or not they had perceived a shine-through element

Onset difference (ms):	−80	−60	−40	−30	−20	−10	0	10	20	40	80	160
Observer												
NO	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
SM	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
AD	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
TK	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
GV	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No

Binary responses of yes and no were strictly enforced.

tween context and kernel). With increasing and decreasing onset difference, performance deteriorates strongly, saturating at onset differences of about −60 and 40 ms.

Performance for a vernier with a grating of only five elements is about 214″ (standard error of about 46.6″), i.e. significantly lower than in the condition in which all elements of the grating appear simultaneously [mean 51″ (standard error: 5.7)]. Hence, the context is necessary for shine-through to occur. None of the observers perceives shine-through with only the kernel indicating that differences in the onsets of context and kernel disturb shine-through, which otherwise occurs for gratings with more than five elements.

For large onset differences (above about 40 ms onset difference), subjects see the context to appear at a clearly different time than the kernel. For most subjects, shine-through is completely abolished under these conditions. Table 1 shows subjective reports regarding whether or not subjects perceive shine-through. Results are heterogeneous, but they covary well with performance. Reports are consistent in the sense that a subject never reported shine-through in a condition in which performance was below another one for which no shine-through was reported. Observers' reports in the following experiments are also heterogeneous but consistent; we avoid presentation of tables with subjective results there.

2.3. Varying context offset

The results of the last experiment show that even tiny onset differences between context and kernel can deteriorate performance significantly (see Fig. 4). In this experiment, we investigate the effects of context duration, hence offset differences, on perception and performance.

2.3.1. Material and methods

For four out of five observers, the vernier appeared for 20 ms, immediately followed by kernel and context, i.e. 23 elements appeared simultaneously. For the remaining subject, the vernier was displayed for 30 ms. Kernel elements lasted for 300 ms as usual. The duration of the context varied, i.e. the elements disappeared earlier than or simultaneously with the kernel (see Fig. 3B). As in the last experiment, subjects had to indicate the direction of vernier offset. After a block was finished, subjects had to report whether or not they had perceived shine-through.

As a control, we repeated the last experiment varying context onset to ensure that subjects participating in this experiment also revealed the strong dependency on context onset difference. Only context delays of 10 and 20 ms were tested.

2.3.2. Results and discussion

As can be seen in Fig. 5, performance improves monotonically with increasing display time of the context saturating at about 150 ms. The results show that a simultaneous onset of context and kernel is necessary, but not sufficient, for optimal performance. For a context duration of 50 ms thresholds are significantly

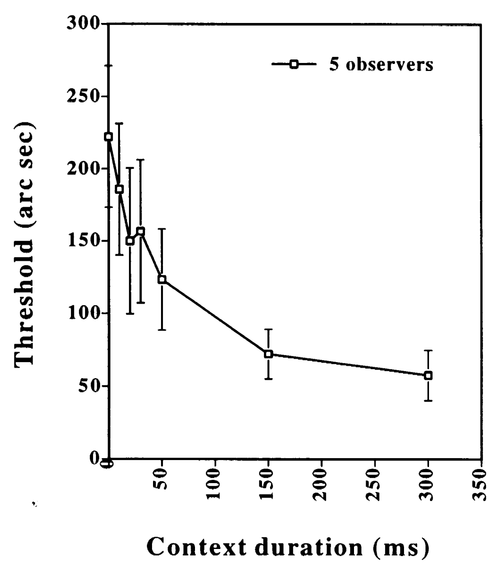

Fig. 5. The temporal offset of context was varied. The context was presented at the same time as the kernel but disappeared earlier than or simultaneously with the kernel. The abscissa shows the duration of context. For a value of 300 ms, context and kernel disappear simultaneously. Performance improves with longer presentation times of context.

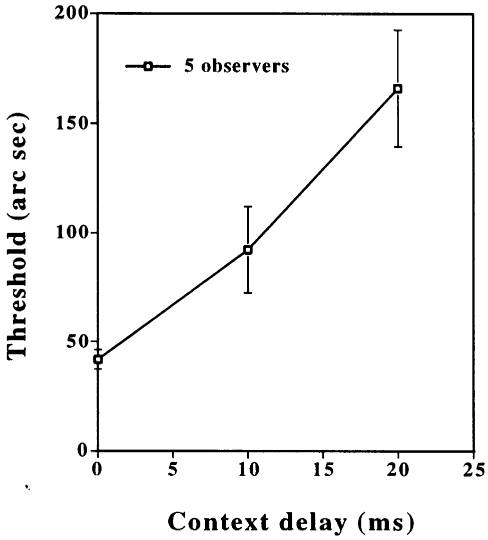

Fig. 6. Experiment 2 (see Fig. 4) was repeated for delays of 10 and 20 ms and a limited range of onset differences (here: context delays) to ensure that a context delay deteriorates performance also for the new subjects joining experiment 3. Again, non-simultaneous presentation strongly increases thresholds.

better compared to the condition in which no context elements are presented (paired t-test: $P = 0.033$). Shine-through occurs for all subjects if the context is presented for at least 30 ms.

The control shows that, as in the preceding experiment 2, delays of 10 and 20 ms deteriorate performance significantly also for this new group of observers (see Fig. 6; paired t-test: $P = 0.0388$ for simultaneous presentation vs. 10 ms delay).

2.4. Filling the gap: varying onset

As shown in Herzog et al. (2001), introducing a gap between kernel and context may render the vernier invisible and dramatically deteriorate performance.

In this experiment, we combined spatial and temporal aspects. Elements filled the gaps in the grating at variable times. The other two times eight context elements were presented simultaneously with the kernel (see Fig. 7A). The question is: how much do the elements filling the gaps contribute to shine-through?

2.4.1. Material and methods

We presented the context exactly one additional element spacing apart from the kernel thus creating two gaps of 400″ total width. At the position of the gaps, standard grating elements, differing from the other grating elements only in their temporal onset, were displayed (see Fig. 7A). For negative onset differences, these elements appeared before the kernel and the other context elements and may even have preceded the vernier for onset differences larger than 20 ms (for one observer, larger than 30 ms). We tested a smaller set of onset differences in this experiment compared to the one varying the onset of the whole context.

A control was conducted using a grating comprising only seven elements appearing all simultaneously. In another control, performance was determined with no elements in the gaps.

2.4.2. Results and discussion

As in the analogous experiment 2, the above performance deteriorates with increasing onset difference (Fig. 8). It is remarkable that the overall results of this experiment and the experiment varying onset of the whole display are very similar. For small onset differences, performance is almost comparable to the condition in which the onset of the whole context varies (compare Figs. 4 and 8).

To determine the relation between these two conditions quantitatively, we determined performance with new tests for four observers (two of which did not participate in the earlier experiments) for onset times of

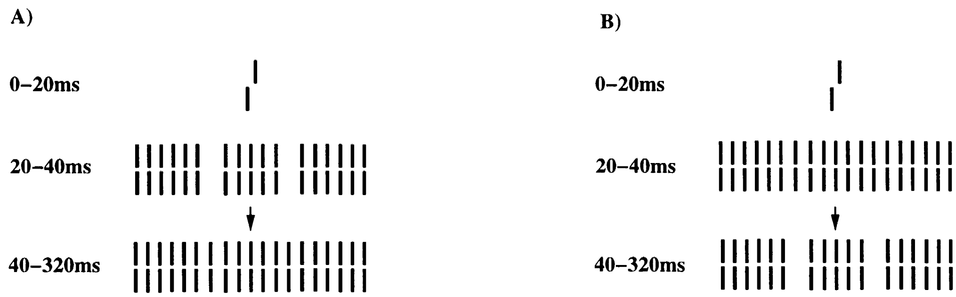

Fig. 7. Temporal order of filling the gaps. (A) In the experiment varying the temporal *onset*, the vernier was replaced without ISI by the kernel and eight outer context elements, creating a grating with two gaps. After a delay, in this figure 20 ms, two additional elements filling the gaps were presented (and all 23 grating elements were on display). Context, kernel, and gap filling elements disappeared simultaneously. Note that the 'filling' elements could also appear before or at the same time as the vernier. In this case, the elements 'pre-filled' the gaps, which appeared later. (B) After the vernier disappeared, all 23 elements of the grating were displayed simultaneously in the experiment varying the temporal *offset* of the elements filling the gaps. The duration of the two single elements varied. Zero ms (Fig. 9) means that no single elements were displayed, i.e. the grating had two gaps for 300 ms. For short presentation durations, the elements in the gaps themselves were almost invisible.

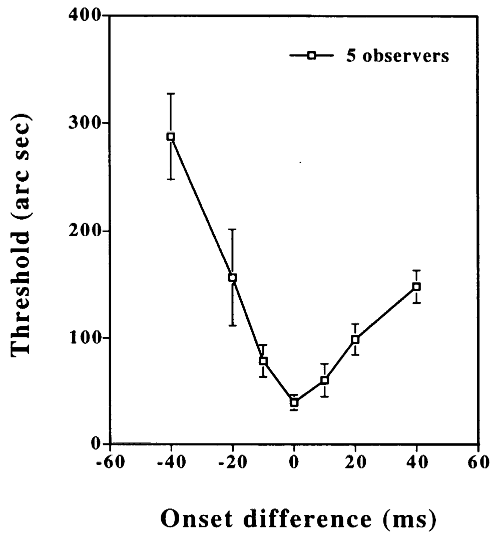

Fig. 8. A vernier was presented followed immediately by the kernel and all but two context elements. We varied the temporal onset of two context elements, namely the elements closest to the kernel (see Fig. 7A). The abscissa shows the temporal onset differences of these two elements in relation to the kernel (and the other context elements). Positive values indicate a delay of the two elements and negative values indicate that these elements appear before the kernel. The overall shape of this curve looks very similar to the curve of the experiment in which the onset of the *whole* context is varied.

Table 2
Performance for onset differences of context and gap elements

Onset difference:	−20 ms	0 ms	20 ms
Condition:			
Context	196.8″ (61.6)	39.0″ (9.8)	116.7″ (25.0)
Gap	236.5″ (66.4)		122.0″ (43.7)

Gap elements or the whole context preceded (−20 ms) or followed (20 ms) the grating by 20 ms or were presented simultaneously (0 ms), in the standard condition, i.e. identical for the gap and context condition. For each condition, the mean threshold (arc sec) and standard error (in brackets) are shown.

−20, 0, and +20 ms (see Table 2). While data are noisy, mean values do not reveal any significant differences between 'context' and 'gap' conditions. Therefore, it seems that onset differences of two context elements yield the same interference with shine-through as onset differences of the whole context.

A grating comprising seven elements or containing gaps leads to a performance significantly lower than the standard condition [thresholds and standard errors: 224″ (standard error: 51.9) for a seven element grating, 185″ (standard error: 28.8) for a grating containing gaps, and 40″ (standard error: 7.0) for the standard condition]. Moreover, shine-through is not, or only weakly, perceived for the seven element grating and the grating containing gaps. Therefore, one can assume that deterioration of performance and diminishing of shine-through are due to the fact that the two elements fill the gaps. This result cannot be attributed to the assumption that the onset difference of the 'filling' elements disturbs shine-through occurring for a grating comprising seven elements. It seems that differences of temporal onsets hinder grouping of the grating as a whole since, for example, the delayed single elements may segment the kernel from the context.

2.5. Filling the gap: varying offset

This experiment is the 'gap analog' to experiment 3, varying the temporal offset or the duration of the whole context. As in experiment 4, not the whole context is varied but only the offset of two single elements filling the gaps.

2.5.1. Material and methods

Identical parameters as in the preceding experiment were used, except that the temporal offset of the gap elements varied (see Fig. 7B). Hence, the elements in the gaps appeared at the same time as all other grating elements but disappeared at earlier times (except in the 300 ms delay condition where all grating elements disappeared simultaneously).

2.5.2. Results and discussion

With increasing presentation time of gap elements, performance improves and thresholds decrease (Fig. 9). As for the onset conditions, the overall results of 'gap' and 'whole' context conditions are very similar.

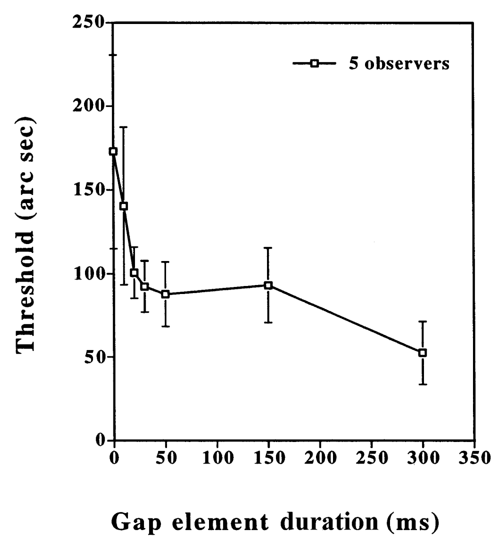

Fig. 9. All elements of the grating appeared at the same time immediately after the vernier's disappearance (see Fig. 7B). We varied the temporal offset of the two elements of context closest to the kernel (gap elements) analogously to experiment 4. The abscissa shows the duration of these elements. A zero duration means the grating contains two gaps throughout its presentation time, i.e. no gap elements. For a duration of 300 ms, all elements of the grating disappear simultaneously.

To investigate the relation between these two conditions quantitatively, we determined performance in the 'context' vs. 'gap' conditions for four obervers (one of them 'new') for grating durations of 30, 50 ms, and the standard condition, i.e. 300 ms duration (see Table 3). As in the comparison of 'context' vs. 'gap' conditions in the last experiment, almost no difference in performance was found between these conditions. Therefore, differences in duration of two context elements can interfere with shine-through as strongly as differences in duration of the whole context.

3. General discussion

3.1. Temporal aspects

As shown in the companion publication describing the spatial aspects of shine-through (this issue of Vision Research), subtle changes in the geometry of the standard grating diminish or even abolish shine-through and deteriorate performance. In this publication, we show that also the temporal characteristics of the grating play an important role for shine-through to occur. Delaying the temporal onset of the context by only 10 ms leads to a strong and significant reduction of performance. In terms of the underlying neural activity, 10 ms correspond to only one burst or a few spikes. It seems that not only the spatial homogeneity of the grating but also its temporal homogeneity plays an important role. It is important to note that the different temporal onsets occur between context and kernel, which are quite separate from the target vernier. As shown in Herzog and Koch (2001), in feature inheritance, the focus of attention is narrower than the distance between the vernier and the context. Therefore, the temporal simultaneity may play an important role for pre-attentive grouping of elements (see also Lee & Blake, 1999; Kandil & Fahle, 2001).

Simultaneity of kernel and context is a necessary, but not sufficient, condition for optimal performance. If the context appears simultaneously with the kernel, but for only a short duration, performance still strongly deteriorates, and shine-through diminishes. Therefore, the timing of both onsets and offsets is crucial for shine-through. These results may reflect the importance of transient neural responses to onsets and offsets of visual stimuli. Using a metacontrast paradigm, Macknik and Livingstone (1998) showed that the visibility of a target line masked by two parallel bars depends strongly on both a neural onset response and an after-discharge signal corresponding to the temporal offsets of the stimulus. Di Lollo, Enns, and Rensink (2000) showed that, in the common onset masking paradigm, mask and target do not interfere if they appear and disappear simultaneously. However, if the mask lasts longer, performance deteriorates strongly.

Table 3
Performance for offset differences of context and gap elements

Duration:	30 ms	50 ms	300 ms
Condition:			
Context	101.7″ (24.5)	109.1″ (31.2)	42.7″
Gap	103.3″ (22.9)	93.0″ (33.3)	

Gap elements of the whole context lasted for 30, 50, or 300 ms, i.e. we used the standard condition. For each condition, the mean threshold (arc sec) and standard error (in brackets) are shown.

3.2. Vernier duration

It is often difficult to find the exact presentation time for which shine-through occurs for individual observers due to the limited temporal resolution of the experimental set-up. Most untrained observers do not experience shine-through for a vernier display time of 10 ms but perceive it for 20 or 30 ms presentations. However, preliminary results show that some observers perform quite well even for durations below 10 ms after extensive training. As shown in Fig. 2, the effect of vernier duration is based both on the display time itself and on the increased energy caused by longer durations. Bloch's law applies regarding the luminance effects themselves, i.e. about the same performance is reached if the vernier is presented with doubled luminance or for doubled duration. A grating presented after a blank inter-stimulus-interval yields a better performance than an immediately following grating, indicating a positive effect of additional processing time.

The signal-to-noise ratio of single cell responses in the awake monkey's inferior temporal cortex deteriorates strongly for masked stimuli, displayed for 20 ms, and performance in a corresponding discrimination task is close to chance level (Kovacs, Vogels, & Orban, 1995; see also Rolls & Tovee, 1994). For longer presentation times, both the signal-to-noise ratio and the behavioral performance improve. Analogous processes may underlie the masking of the vernier by a small grating. However, different mechanisms seem to produce shine-through, since vernier presentation times can be as short as 10 ms and still allow discrimination of small spatial offsets.

3.3. Feature inheritance and shine-through

For most observers, shine-through operates on a different time scale than feature inheritance. For example, most subjects perceive shine-through (which is a sign of feature separation) very clearly with a 20 ms vernier presentation time but are hardly able to perform feature inheritance (a sign of feature binding), which might require at least 30 ms presentations. Therefore, it seems that feature binding in small spatio-temporal windows requires more time than feature separation in our paradigm (see also Herzog & Koch, 2001; Herzog et al., 2001).

In conditions with delayed context, many observers perceive the whole kernel as offset, i.e. similar to feature inheritance. But in contrast to feature inheritance, it seems that observers do not focus on one of the outer edges. Perceiving feature inheritance might be one reason why performance deteriorates, but discrimination is still possible for short onset differences. Taking into account all the subtle spatial as well as temporal requirements for shine-through to occur, it seems that shine-through is an exception rather than the rule. Very small parametric deviations lead to dramatic masking of the target.

3.4. Backward masking

Feature inheritance and shine-through belong to the category of backward masking phenomena (e.g. Breitmeyer, 1984; Bachmann, 1994; Enns & Di Lollo, 2000). As preliminary data show, they reveal A-type masking characteristics, i.e. performance improves with increasing SOA (stimulus onset asynchrony). The shine-through effect shows that masking cannot be explained by local mechanisms alone because the central part of our masking stimulus is always the same, while the spatial layout of context elements has a decisive influence. Therefore, models focusing exclusively on local processing cannot completely explain our results (for a recent review, see Breitmeyer & Ogmen, 2000; cf. also Purushothaman, Ogmen, & Bedell, 2000). Also, purely first-order energy models encounter enormous problems in explaining these phenomena. Contrary to these models' predictions, increasing masking energy, i.e. adding more grating elements, yields better performance (For a very similar metacontrast result see Breitmeyer, 1978). Another class of models explains masking by missing facilitation due to mis-allocation of conscious resources instead of inhibition, suppression, or interruption between neural activity corresponding to mask and target elements (Bachmann, 1994). However, this model also bases on retinotopic local processing. It is worth noticing that our results do not imply that local mechanisms and conscious resources do not play a role in the shine-through effect. But our data suggest that also other mechanisms may be involved.

Preliminary results show that simultaneous masking paradigms (e.g. Westheimer & Hauske, 1975) and the backward masking effects of feature inheritance and shine-through cannot be directly related. However, our results provide further evidence that vernier processing itself cannot be explained by purely local mechanisms as already suggested by Westheimer and McKee (1977). These authors showed also that unmasked vernier thresholds are not affected when the two segments of a vernier are presented delayed up to 20 ms relative to each other — hence, subtle time differences are not important for vernier discrimination as such.

3.5. Segmentation

As discussed in the companion paper and as seen in Fig. 9, inserting gaps into the grating strongly diminishes performance. Likewise, other spatial manipulations disrupting the homogeneity of the grating interfere strongly with shine-through. We argued that segmentation processes relating to the grating determine the degree of shine-through and, hence, the level of performance. Once segregated, small gratings do not allow shine-through but may yield feature inheritance. We find here that also temporal characteristics, such as context delay, may segment the grating into parts and hence interfere with shine-through. This segregation depends on local coupling between grating elements since the delay of single elements can yield results quite similar to delaying the whole context (see Figs. 8 and 9). These segmentation processes seem to emerge very early during the time course of visual information processing.

Segmentation may require recurrent neuronal connections and can be explained by reentrant architectures (Di Lollo et al., 2000). We found that, for most observers, the influence of the spatial layout arises only for gratings lasting longer than 40 ms (Herzog & Fahle, 2001). However, the strong dependency on context onset may be best explained by lateral interactions of neurons or by an interaction of transient and sustained neuronal channels (Breitmeyer, 1984; see Herzog, Koch, & Fahle, in press). Please note that single context elements are only 200″ apart from their neighbors, i.e. clearly less than the diameter of on-regions of most receptive fields of simple cells in the primary visual cortex (V1).

These ideas, of course, are highly speculative, and other mechanisms might explain the results as well. For example, onset differences may lead to motion signals at the borders between context and kernel, which could mask the shine-through element (see e.g. Kahneman, 1968). Since onset differences of elements in the gaps produce the same motion signals as onset differences of the whole context, the degree of interference would be identical. Such a scenario would imply that masking occurs independent of the direction of motion since interference is found for contexts preceding as well as following the kernel.

3.6. Feature binding

In feature inheritance, only one 'object', the grating, is perceived, which inherits the offset of the foregoing vernier (feature binding), while in shine-through, two 'objects' are visible, each having its own features (feature segmentation). Therefore, we are able to switch between two states of feature binding at one spatial position by changing only context elements displayed at another spatial position (see Herzog et al., in press).

Our results may contribute to the discussion about neural theories of feature binding via temporal mechanisms (e.g. see von der Malsburg, 1995 and Roskies, 1999). As shown, simultaneous presentation of stimulus elements plays an important role for shine-through. However, it is difficult to imagine how oscillations, of whatever reasonable frequency, can support vernier coding since the vernier is masked, and its duration is shorter than a cycle of, for example, a 40 Hz oscillation.

It remains an open question whether the lack of onset simultaneity or else the delayed onsets of the context disturb shine-through and performance in the delay conditions: does shine-through fail because all elements of the grating have to be bound together by a mechanism requiring simultaneity? Or does shine-through fail because, for example, context delay induces 'unexpected' new onsets that disturb processing of the old onsets as backward masking or trans-cranial magnetic stimulation do.

In the feature inheritance effect, properties such as vernier offset are mis-localized, i.e. they are 'freed' from their carrier — the vernier. Evidence for feature perturbations and migration were described in a couple of other phenomena by Wolford and Shum (1980) as well as Butler, Mewhort, and Browse (1991). Treisman and Schmidt (1982) showed that under heavy attentional load, illusory conjunctions occur, i.e. features of one object are attributed to another not possessing these properties at all. Our results add a new and precisely measurable effect to these examples of feature migration.

3.7. Summary

The complementary backward masking effects features inheritance and shine-through may become useful tools in investigating such different topics as time course of processing, feature binding, attention, masking, and even consciousness. One noteworthy feature of these effects is that the observer's processing time is strongly limited due to short display times but still spatial parameters, e.g. vernier offset, are in a very reasonable range, i.e. smaller than 60″.

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