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ORIGINAL ARTICLE

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Experiments on the Fehrer–Raab effect and the 'Weather Station Model' of visual backward masking

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Abstract The Fehrer–Raab effect (simple reaction time is unaffected by metacontrast masking of the test stimulus) seems to imply that a stimulus can trigger a voluntary reaction without reaching a conscious representation. However, it is also possible that the mask triggers the reaction, and that the masked test stimulus causes a focussing of attention from which processing of the mask profits, thus reaching conscious representation earlier. This is predicted by the Weather Station Model of visual masking. Three experiments tested this explanation. Experiment 1 showed that the masked test stimulus caused a temporal shift of the mask. Experiment 2 showed that the reaction in the Fehrer–Raab effect was not exclusively triggered by a conscious representation of the test stimulus: the mask was involved in evoking the reaction. Experiment 3 again revealed a temporal shift of the mask. However, the shift was only about half as large as the Fehrer–Raab effect. The psychometric functions suggested that the observers used two different cues for their temporal order judgments. The results cast doubts on whether judged temporal order yields a direct estimate of the time of conscious perception. Some methodological alternatives are discussed.

Introduction (see endnote 1)

The experiments reported here are concerned with an old problem. Ninety years ago, the German psychologist Hugo Münsterberg asked "... whether the ultimate psychological products elicited by images of voluntary movements may be achieved without conscious will, whether these higher intellectual functions may, under certain circumstances, be produced without conscious apperception" (Münsterberg, 1889, p. 67).

This question concerns the relation between the *representation* of cognitive contents (conscious or not) and the way in which they may be *functionally effective*. How can a cognitive content be effective without being consciously represented, and which of its functional consequences require that it has reached the level of conscious representation?

Münsterberg's answer was in radical contrast to the prevalent opinion of his days, as it still is. On the basis of reaction time experiments, he concluded that a stimulus cannot only elicit associative processing before being consciously perceived, but also a motor response: "We usually have already started responding to a stimulus when we apperceive it; our motor apparatus does not wait for our consciousness, but fulfils its duty restlessly and our consciousness watches it and is not allowed to give orders" (Münsterberg, 1889, p. 173). A modern type of experiment seems to support Münsterberg in a surprising manner.

The Fehrer–Raab effect

If two stimuli follow one another at the same or an adjacent location with a short temporal delay, masking occurs. Metacontrast (see, e.g., Alpern, 1953; Breitmeyer & Ganz, 1976; Lefton, 1972; Neumann & Scharlau, this volume; Weisstein, 1972) can be observed if the mask is laterally adjacent to the test stimulus, for example if a disc is followed by a surrounding ring. With SOAs (stimulus onset asynchronies) of 40–80 ms, the test stimulus may be completely masked.

Simple reaction time (RT) to visual stimuli increases with decreasing luminance (see, e.g., Teichner & Krebs, 1972). Thus, the reduced brightness that accompanies metacontrast and may lead to phenomenal disappearance, should increase RTs. Fehrer and Raab (1962) investigated this, with a surprising result: Despite masking, RTs were not prolonged. With short SOAs, masking even

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appeared to reduce latency. Fehrer and Biederman (1962) and Schiller and Smith (1966) confirmed this finding.

The problem

Strikingly paradoxical results like these invite scepticism. Could the Fehrer–Raab effect be an artefact? Has the test stimulus in these experiments actually been completely masked? Fortunately, this question, which may easily lead into sterile arguments about how 'subliminality' of a stimulus can be ascertained, is irrelevant: A naïve subject can display the Fehrer–Raab effect even if he believes to respond only to the mask and knows nothing of the test stimulus (Fehrer & Raab, 1962). Under the same circumstances, discrimination performance of a trained person can be considerable (Bernstein, Amundson, & Schurman, 1973). Thus, the masked stimulus may be detect*able*, but the Fehrer–Raab effect does not depend on its being actually detected. Whether or not this is termed 'subliminal' is a terminological question.

In any case, the entire literature on metacontrast demonstrates that the visibility of the test stimulus is most severely reduced. Yet RTs are unaffected by masking, implying that the motor response is elicited by an independent effect of the test stimulus which is not subject to masking. What is this effect, and does it imply that a stimulus elicits a voluntary movement without being consciously represented as suggested by Münsterberg?

An explanation

The Fehrer–Raab effect may be explained without Münsterberg's hypothesis: Observers might respond to the mask, and not to the test stimulus. The speeding up of the response by a preceding test stimulus may be due to the fact that the mask is perceived faster and can thus be responded to more quickly.

Here is a model which assumes that a masked stimulus speeds up the processing of the mask: To consciously perceive a stimulus, the observer has to allocate attention to its location in the visual field. We term this process 'focussing' of the stimulus. In partial-report experiments, this focussing is initiated by a special indicator stimulus, for example an arrow. If only a single stimulus is presented, it must itself elicit the process by which it is focussed. This reminds of Münchhausen's ability to draw himself out of the swamp by pulling his own braid. Upon closer inspection, it is less remarkable.

Strictly speaking, 'the stimulus' is an abbreviation, especially with respect to its physiological representation. Presenting a stimulus elicits activity in separate neuronal 'channels' which differ in their sensitivity to temporal and spatial frequencies (cf., e.g., Breitmeyer & Ganz, 1976; Cornsweet, 1970; Legge, 1978). So-called transient channels are specialized for conveying temporal changes but only process lower frequencies in the spatial domain. These channels are fast; their activity reaches cortical levels about 50–100 ms earlier than the activity of sustained channels which are specialized for high spatial frequencies. They deliver coarse information about changes in the visual field and hereby elicit an allocation of attention to the respective location. While this focussing process occurs, the activity of the slower, sustained channels will be completed (Breitmeyer & Ganz, 1976), so that the focussing process, when it has reached its destination, comes upon a fully developed representation of the stimulus.

This model can explain the distractor effect in masking (Neumann & Scharlau, this volume), that is, the finding that a distractor displaces the increasing part of the masking function by a constant amount towards larger SOAs. Two stimuli that appear simultaneously at different locations in the visual field elicit two transient responses and hence two competing signals for allocating attention, so that the process of focussing should be delayed. The test stimulus is not immune against masking until it has been consciously attended to. If the distractor delays attention, the temporal range in which the test stimulus is susceptible to masking will increase by the same margin.

This model can be applied to the Fehrer–Raab effect because it contains an assumption about the perceptual latency of the mask: If the mask is presented singly, its presentation triggers the focussing process. If it is preceded by a test stimulus, focussing starts with the presentation of the *test stimulus*, that is, it is shifted forward in time by the interval between test stimulus and mask. If the mask replaces the test stimulus during focussing, the mask should be consciously represented earlier compared to a condition in which allocating attention is caused by the transient activity which is elicited by the mask itself. The speed-up of its perception should be exactly equivalent to the SOA between test stimulus and mask, because this is the amount by which the focussing process should be pre-dated.

The following analogy may illustrate this model. Imagine an operator supervising his instruments on a weather station. He is unable to pay attention to all of his instruments simultaneously. Yet this is not necessary, because the instruments only occasionally signal new values. In order to avoid missing a change, the instruments acoustically signal that a change takes place (transient response). Some time elapses before the operator moves his head and adjusts his spectacles in order to read out the display (focussing). If an instrument changes its display twice within a short interval (masking), the first change triggers the signal and elicits the focussing, but before the operator is able to read out the changed value, it has been replaced by still another one. The first value is inaccessible to the operator; it is 'masked'.

Let us suppose further that immediately after the read-out, the operator types a message into the telex (motor response). Usually, say, a minute elapses between the change of the instrument's display and the moment at which the telex is operated—30 s which the operator needs to turn to the instrument and 30 s for read-out and other actions. Suppose that two changes of the display take place within 10 s. The acoustic signal elicited by the first change (the transient response) causes the operator to look at the instrument 30 s later, but at this time the instrument will be displaying the re-changed value for 20 s. To this value (the only one of which he is 'consciously aware') the operator responds; and his 'response latency' is not, as usual, one minute, but only 50 s. To an external observer the operator seems to have responded to the first change of the instrument; but he himself believes to have responded to the second change. This is equivalent to the Fehrer–Raab effect as interpreted here.

Experiment 1

In order to test the hypothesis that a masked and invisible stimulus shifts the point in time at which the mask is consciously registered, we used an identical standard stimulus, not affected by the illusion, and determined the point of subjective simultaneity (PSS) between standard and metacontrast mask.

Method

Masking was produced with the disc-ring display. The mask was a ring just under 1° to the right of fixation; the test stimulus was a preceding disk with a diameter identical to the inner diameter of the ring. These stimuli were presented at approximately 1.8 cd/m^2 on a dark background (see endnote 2); exposure duration of the mask was 10 ms, that of the test stimulus was 2 ms. The SOA between test stimulus and mask was 80 ms. The further presentation conditions were as described in Neumann (1978; Neumann & Scharlau, this volume). Masking was virtually perfect. To the left of fixation, the standard stimulus—a ring identical to the mask—appeared at the same distance of roughly 1° (see endnote 3). The SOA between the mask and the standard stimulus was varied between -80 and +80 ms in steps of 20 ms. In half of the trials, the test stimulus preceded the mask; in the other half (baseline condition), only the mask was presented to the right of fixation. In both the experimental and the baseline condition, each of the 9 SOAs was presented 80 (observer W.S.) or 32 times (observer O.N.). The task was to report which of the two stimuli appeared first.

Results and discussion

The results are depicted in Fig. 1. The predicted effect is qualitatively present. If the mask is preceded by a masked test stimulus, it is temporally displaced. Quantitatively, the finding is, however, less satisfactory: we expected that the mask would be seen exactly at the time when the test stimulus was presented. This is not the case. Instead of 80 ms, the shift is approximately 45 ms for W.S. and 40 ms for O.N. Several explanations can account for this. One possibility is that it is due to the time parameters: we used the very large SOA of 80 ms between test stimulus and mask. To achieve perfect masking with this SOA, the exposure duration of the test stimulus had to be very short (2 ms). Thus, the test stimulus might have been processed slower than the mask. A further possible reason is the range of standard stimuli. In order not to induce a bias in favour of our hypothesis, the SOAs were distributed symmetrically around the point of objective simultaneity. With a temporal displacement of the size of the SOA of 80 ms between test stimulus and mask, this would have meant that in the experimental condition, the subject would nearly always have had to judge 'right'—against the well-known tendency to equally distribute the judgments. The next two experiments attempted at observing the Fehrer–Raab effect and the temporal-displacement effect under as similar as possible conditions.

Experiment 2

In this experiment, the Fehrer–Raab effect was measured. Besides providing a comparison for the temporal-displacement effect, the experiment was based on the following idea: If the subject responds to the conscious representa-

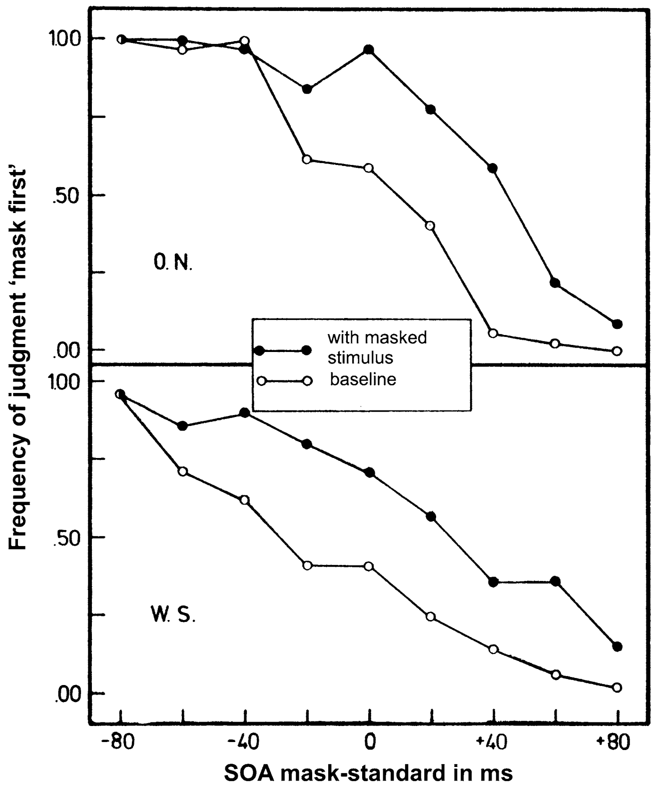


Fig. 1 Judgments on the order of two rings depending on a masked disc which preceded the ring on the right side. In the baseline condition, only the two rings were presented (*open symbols*). In the experimental condition (*filled symbols*), the right ring was preceded with an SOA of 80 ms by a disc. Depicted is the frequency with which the mask was perceived as first one. *Negative SOAs* mask is presented before standard

tion of the mask, properties of the mask should influence RT. In the range of stimulus durations of 10–60 ms (depending, for instance, on background intensities, see Roufs, 1972), Bloch's law holds for simple RTs; that is, increasing presentation time entails the same decrease of RT as an increase in luminance that adds the same amount of total energy (Hildreth, 1973). Thus, an increase in exposure duration of the mask in this range should reduce RT. On the other hand, such an increase enhances masking strength. If the response is elicited by some conscious representation of the *test stimulus*, the opposite prediction should hence be true; the reaction should be slower if the mask is exposed for a longer duration.

Pilot experiment

A pilot experiment compared the effect of two different masks. The test stimulus again was a small disc right of fixation. Unlike the masking conditions in the first experiment, it was masked by a larger disc with the same diameter as the outer contour of the ring in Experiment 1. With this exception, the display and other conditions were the same as in Experiment 1. The luminance of all stimuli was approximately 4 cd/m^2. The test stimulus was exposed for 5 ms. The exposure duration of the mask was 5, 10, or 15 ms. There were the 8 SOAs 5, 15, 25, 35, 45, 65, 85, and 105 ms.

Masking strength was measured by a judgment method. Masking strength in metacontrast depends on whether a succession of test stimulus and mask is visible. One of the judgments was about this aspect of masking: "1" if only *one* temporally integrated stimulus was seen, "2" if test stimulus and mask were perceived as successive. The second important cue is the number of perceived contours: in the range of strongest masking with medium SOAs, only the outer contour of the mask is visible; with weaker masking one sees in its centre a more or less distinct second contour, that of the test stimulus. The observer gave a binary judgment on this dimension after each exposure (inner contour yes/no). Each of the 24 combinations of 8 SOAs and 3 exposure durations was judged 12 times by each observer (see endnote 4).

The data of the two observers were very similar and have been summarized in Fig. 2. In accordance with earlier results (Neumann, 1978), the exposure duration of the mask had a marginal influence within the range of temporal resolution, but massively influenced masking when test stimulus and mask were temporally integrated. With 5 ms exposure duration, the observers were able to perceive traces of a contour of the test stimulus with all SOAs. With 10 ms, the proportion of "contour present" judgments was slightly reduced; with 15 ms it varied between just below 50% (SOA 5 ms) and 25% (SOA 45 ms).

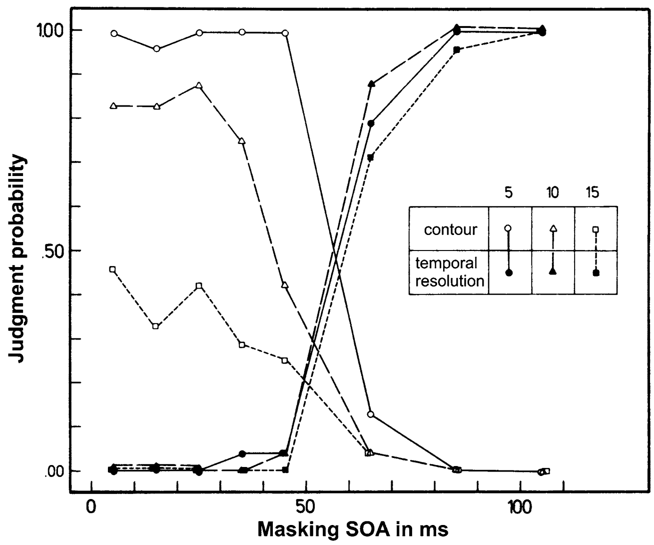


Fig. 2 Data from the preliminary experiment. The observer gave a double judgment, first on temporal resolution ("one" vs. "two"), afterwards on the presence of a contour of the test stimulus in the inner of the mask ("yes" or "no")

Method

On the basis of these data, we chose the conditions for the main experiment. First, the subject should only perceive a single, temporally integrated stimulus. (This will be of critical importance for Experiment 3 on temporal shifts.) This is quite reliable for SOAs up to 45 ms (see Neumann, 1978). We chose the SOAs 5, 25, and 45 ms for the main experiment. Exposure duration of the test stimulus was 5 ms. Second, we wanted to compare two exposure durations of the mask one of which should (1), according to Bloch's law, elicit a faster simple response and (2) have stronger masking effectiveness than the other. In the range of temporal integration, the data from the preliminary experiment revealed a pronounced difference between mask exposure durations of 5 and 15 ms. These exposure durations also fulfil condition (1) (Hildreth, 1973). They were used in the main experiment.

The experimental design thus included 3 (SOAs) × 2 (exposure durations) masking conditions. Three control conditions were provided: presentation of only the test stimulus, or only the mask with the two exposure durations.

Each trial started with an acoustic warning signal. After 700 or 850 ms, either the sequence of test stimulus and mask was presented, or only one of these stimuli was displayed. Two trained observers served as subjects (B.R., female; H.C., male). The subject responded by pressing a morse key.

Results

Mean RTs are depicted in Fig. 3. The Fehrer–Raab effect was replicated fully for observer H.C., for B.R. with the exception that for the two longer SOAs (25 and 45 ms) RT for the combination of test stimulus and mask was slightly longer (between 1.2 and 3.9 ms) than RT to the test stimulus alone. Further, as expected, and corresponding to Bloch's law, RT was slightly shorter for the exposure duration of 15 ms than for the exposure duration of 5 ms. Note that this also holds in the conditions where the Fehrer–Raab effect was present.

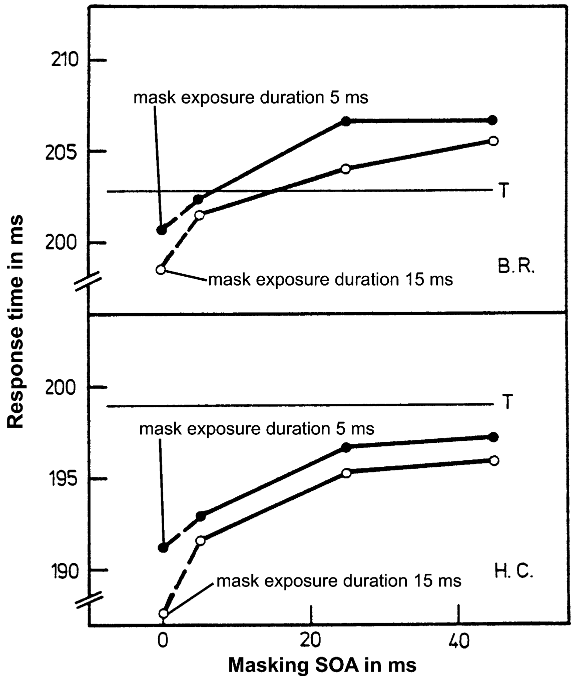


Fig. 3 Reaction times of the two subjects in Experiment 2. *Thick lines* responses to the sequence of test stimulus and mask (except for SOA 0 ms which is the condition "mask alone"). *Thin line 'T'* Response only to test stimulus

The present experiments were designed to test an alternative explanation of the Fehrer–Raab effect according to which the observers respond to the mask and the latency with which the mask is perceived is shortened by the masked test stimulus. If we measure RTs in the present experiment from the beginning of the mask, we find a massive shortening of RTs (compare the thin lines marked 'M15' and 'M5' which indicate the slope of RT function if the observers simply responded to the mask). This effect is present for both observers, although varying in size. The effect of mask exposure duration was additive to this effect of the masked test stimulus. Also, SOA influenced RT, that is, RT was not *exclusively* determined by the test stimulus.

Discussion

The experiment aimed, first, at replicating the Fehrer–Raab effect and, second, at providing information about the influence of test stimulus exposure duration. In general, the replication of the Fehrer–Raab effect was successful. For both subjects, RT to a mask that was preceded by a test stimulus with SOAs of 5 and 15 ms was much slower than RT to the test alone. For the SOAs of 25 and 45 ms, H.C. showed the Fehrer–Raab effect, but B.R. did not. As in the original results (Fehrer & Raab, 1962), RT to the combination of test and mask was even shorter than RT to the test alone.

The finding that the latency was consistently shorter for the 15 ms exposure duration of the mask than for 5 ms is strong evidence that the response was not elicited by a conscious representation of the test stimulus. As the pilot experiment demonstrated, a trace of the test stimulus can be detected almost always with an exposure duration of 5 ms and the SOAs used here, whereas, as a rule, with 15 ms it cannot be perceived. If nevertheless RT in the latter case is shorter, this seems to imply that the motor response does not depend on the representation of the test stimulus on which the judgment of the observer is based.

However, we have also found for all SOAs that the more effective mask (15 ms) shortens the RT as compared to the less effective mask (5 ms). At first sight, this finding seems to be a rather strong confirmation of our initial hypothesis. If the response was elicited by the consciously represented mask and if the test stimulus only pre-dated the beginning of this conscious representation, it would not be surprising that the longer and thus brighter mask lead to shorter RTs.

This result thus fits nicely into our considerations. Still it is not yet a very impressive proof of their correctness. It shows that some representation of the mask that is affected by brightness summation has some impact on RT. But it does not yet prove that this representation is a conscious perception. If the test stimulus can elicit a response *without* being conscious, the mask could equally well do this *before* being consciously perceived. Experiment 3 addresses this topic. It measures the perceived temporal position of the mask with psychophysical methods under conditions which are similar to Experiment 2, so that the results can be directly compared to the RT data.

Experiment 3

Method

We used a single mask exposure duration, 5 ms. The main question—whether the perceived temporal position of the mask is shifted by the test stimulus by the same amount by which the RT is shortened—can be answered without varying exposure duration. We also omitted the condition 'test stimulus alone'. We thus had the following masking conditions: mask alone, masking SOA 5, 25, and 45 ms. (These masking SOAs will be referred to as SOA(M).) Test stimulus and mask were exposed for 5 ms. The stimuli, their position and their luminance were the same as in Experiment 2. In addition, we presented the standard stimulus which was identical to the mask except that it was presented left instead of right of fixation. A further experimental variable was the SOA between mask and standard stimulus, termed SOA (C). It was varied in nine steps of 20 ms between −80 ms (standard leading) and +80 ms (mask leading).

The 36 combinations of 4 SOAs(M) and 9 SOAs(C) were presented 8 times in random order in each block of 288 trials. Each subject (H.C., B.R., and a naïve observer, M.M.) participated in 10 blocks. By judging 'right' or 'left' the subject indicated which of the stimuli was perceived first. Because SOAs(M) fell below the threshold for temporal resolution (see the pilot experiment for Experiment 2), the instruction was unequivocal. Even if a trace of the test stimulus was visible, it appeared as simultaneous with the mask. Each trial was preceded by a warning signal 700 ms prior to the onset of the test stimulus.

Results

Figure 4 depicts the relative frequency of the judgment 'mask first', depending on SOA(C) and SOA(M) for each subject as well as averaged across subjects. Doubtlessly, the leading test stimulus has shifted the perceived temporal position of the mask. The main question, however, concerns the size of this shift.

Originally, we had planned to determine the amount of the shift by a computation of the PSS. This requires a standard psychometric function (a normal ogive). This is surprisingly not the case. A plateau in the centre part of the functions prevents a calculation of the PSS. We thus graphically approximated the shift. The estimates for the temporal shift are depicted in Fig. 5 together with the values of the Fehrer–Raab effect.

Discussion

Although the expected effect showed up, the data are not very satisfactory. First, and contrary to our hypothesis, the temporal shift never reached the size expected on the basis of the RT data, except for SOA(M) 5 ms (see Fig. 5). Second, the psychometric functions were atypical. Third, there were clear differences between the subjects regarding the value of the temporal shift and the deviation of the curves from the typical ogive. The following considerations are an attempt at understanding this pattern of results.

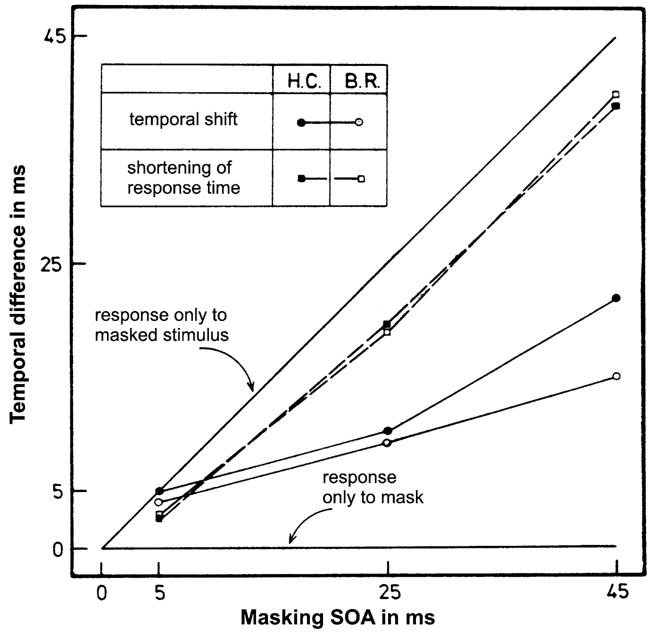
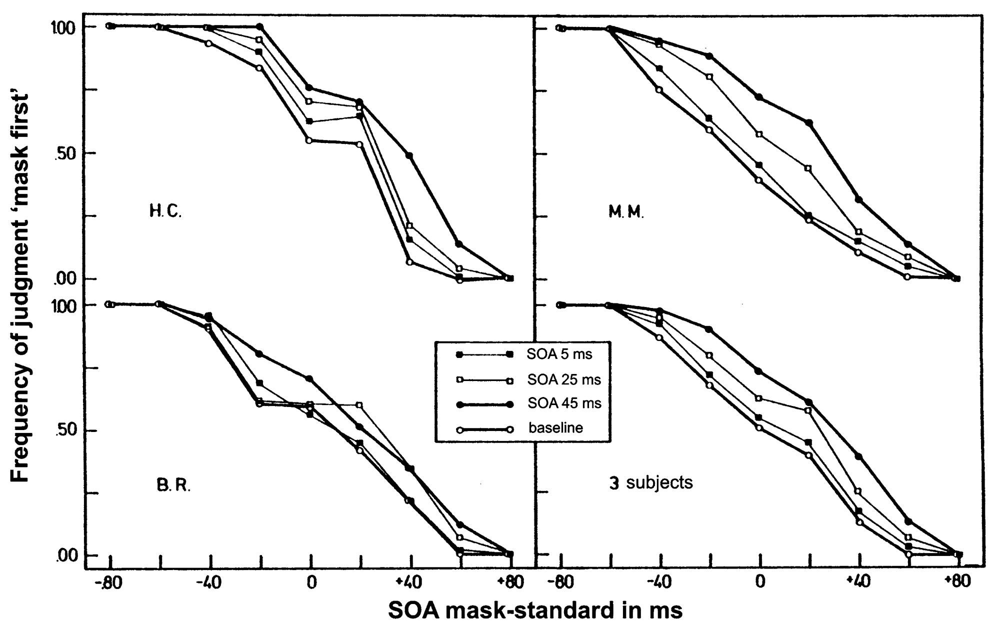


Fig. 5 Comparison of the data of Experiments 2 and 3 for subjects H.C. and B.R. The ordinate gives the latency difference—the amount of time by which the masked stimulus shortened the response (Experiment 2; *dotted lines*) or the value by which the psychometric function was shifted by the preceding test stimulus (Experiment 3; *solid lines*). If the response was only to the mask, the latency difference would be zero. If the response was only to the masked stimulus, it would be identical to the SOA. For the sake of comparison, these values are depicted, too

Perceived temporal order is not 'immediately given'. Like perceived distance in space, it is based on cues. The cues for temporal succession can be of various *nontemporal* origins. The most obvious example is phenomenal location in acoustic space which allows for the discrimination of very small differences in the order of tones. A second nontemporal cue is perceived clarity or intensity,

Fig. 4 Psychometric functions of Experiment 3 separately for the three observers and averaged. On the abscissa the SOA between mask and comparison stimulus (negative SOA: mask leads), on the ordinate the frequency of the judgment 'mask first'). Parameter is the SOA between test stimulus and mask. In the baseline condition, the mask appeared without leading test stimulus



especially if the two stimuli are spatially close to each other. It allows discrimination even with SOAs of a few ms (Efron, 1973; Yund & Efron, 1974). In these cases a temporal feature of the stimuli is represented, but not as a temporal aspect of the phenomenal representation but as a spatial or qualitative property.

Time is not perceived as such, but is the dimension in which perceived *events* take place. We thus have to clarify which kinds of events in the representation of the stimulus sequence allow the subject to correctly judge which of two stimuli came first.

The perhaps simplest case is that the two events are the appearance and disappearance of one and the same object. If they are perceived as successive, an impression of *'duration'* results. If they coincide in the phenomenal representation, a flash is perceived—the object appears and disappears at the same moment (see the excellent study by Piéron, 1923). We found in an unpublished experiment that the threshold for this transition lies reliably at about 60 ms. This value has been confirmed by Servière, Miceli, and Galifret (1977).

If the two transients which mark the beginning and the end of the appearance of a stimulus are closer than approximately 60 ms, they are not perceived as separate events. If the two transients both mark the *onset* of an object at the same location, the second stimulus masks the first one. The threshold for temporal resolution is the same, about 60 ms (Fig. 2).

We can now return to the peculiar form of the psychometric function found in Experiment 3. If the subjects exclusively used the cue 'change', they would have to guess for SOAs below 20–30 ms since, according to Servière et al. (1977) these values are below the threshold for duration. Thus, the psychometric function should be flat in the range of −20/30 to +20/30 ms. This is what we found in our experiment, albeit as a tendency.

The problem thus is reversed: We do not have to explain the deviation of our curves from the normal ogive, but the small amount of this deviation. Apparently, a further cue must be available in our displays.

In order to judge correctly, it suffices to know that one of the stimuli—say the right one—is *the first one*. The event represented cognitively can be this kind of 'right appearance first', in which the second stimulus need not be included at all.

The functional basis for this cue could be the process that we illustrated with the example of an operator in a weather station: the allocation of attention towards a location at which—signalled by the activity of 'transient' neuronal channels—a change took place. We hypothesized that the operator is informed about the change by an acoustic signal and that it takes him some time to focus on the particular instrument. If the display changes again while he turns towards the instrument, this is hidden from him, and the result of the first change is 'masked'. Further, we assumed that an acoustic signal from a different instrument remains undetected within this period of time. However, if we ask the operator which of the instruments—the one which he turned to or another one—changed first, he will answer the question correctly. He will say: it must be the one which I turned to first, because if it would have been the other, I would have focussed on that one.

The shape of the psychometric function in our experiments thus can be interpreted as the combination of the two ideal curves in Fig. 6. If the order judgment was exclusively based on a cognitively represented event of 'change', we should find the shape depicted in Fig. 6a. If the observer based his judgment exclusively on which of the two stimuli first captures attention, the shape should be as in Fig. 6b. Apparently, both types of cues are relevant, and weighted individually for each subject, as the individual differences in the shape of the psychometric functions suggest (Fig. 4).

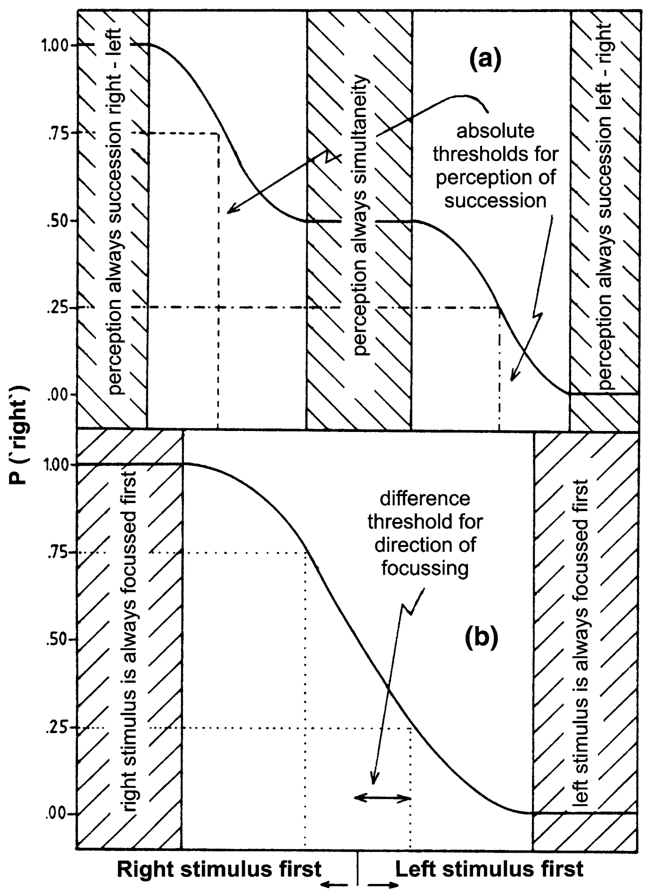


Fig. 6 Hypothetical psychometric functions for the temporal order judgment. In the first case (above), we assume that the observer bases his judgment on the perception of succession 'right to left' or 'left to right'. There is an *absolute threshold* for perception of succession. This threshold function is bordered by two regions. In one of them, simultaneity is perceived always. In the other, succession in the one or other direction is perceived. In the second case (lower part), we assume that the observer will denote the stimulus first which first captured his attention. Here, the threshold function is an ogive which is bordered by regions in which either always the right or always the left stimulus captures attention. The difference limen indicates how exactly the perceived direction of focusing indicates the location of the actually first stimulus

General discussion

Contrary to our initial assumption, the judgment of the observers does not directly reflect the temporal delay between the conscious representations of the stimuli. This delay is defined in the physical reference system of an external observer—at least in our context which is concerned with the explanation of RT differences. By contrast, temporal differences that are determined in psychophysical measurements belong to the frame of reference of psychological time, in which events take place that are cognitively represented for the observer.

Moreover, in a psychophysical experiment, the observer does not provide information about the temporal order of his *cognitive representations*, but about temporal properties of their *contents*. Thus, the temporal delay between two representations, in which we were interested, cannot (or at least need not necessarily) be the object of his judgment. Hence, a psychophysical measurement as in Experiment 3 is not apt to test the Weather Station Model as directly as we hoped. However, we can derive some suggestions from the results.

The subject in Experiment 2 responds to the consciously represented mask which is pre-dated by the leading test stimulus. The size of this pre-dating effect corresponds to the SOA between test stimulus and mask. The judgment in Experiment 3 depended, according to our interpretation, on two cues, the perception of a succession of mask and standard stimulus on the one hand, and the perceived direction (to mask or to standard stimulus) in which attention was initially shifted by the onset of the sequence.

If the cue 'direction of attention' is used, the psychometric function should be shifted by the whole SOA between test stimulus and mask. This was not the case, possibly because this cue was not sufficiently used. This is supported by the finding that subject M.M. who (in accordance with such a strategy) had the smallest plateau in the centre of the psychometric function also showed the most prominent shift.

We thus have to explain why the shift is smaller if the subject more often used the cue 'perceived succession' for the judgment. Let us just suggest a possible explanation. First, according to the Weather Station Model, the onset of the conscious representation of the mask, but not its offset is pre-dated. The perceived duration of the mask should hence be prolonged. If the observer used both points in time for his judgment by referring to the temporal centre between the beginning and the end of the representation of the mask, the temporal displacement should be half of the Fehrer–Raab effect. This is approximately what we found (see Fig. 5).

Second, the perception of succession may be independent of attention. Possibly, the information which is temporally represented as perceived succession is mediated by processing channels which are partially or totally insensitive to attentional effects.

Further, there are considerable logical doubts as to whether our initial question can be answered by a comparison of RT data and data from a psychophysical threshold experiment. The construct 'time of perception' cannot be adequately operationalized by experiments studying the perception of time.

In sum, the present experiments prove that pre-dating of the perception of the mask cannot explain the Fehrer–Raab effect, because it is smaller than that expected on the basis of the RT data (see endnote 5). Thus, we have to search for a further mechanism that might explain the Fehrer–Raab effect. One possibility would be that nonconscious stimuli are processed in a way that allows to respond to them without (or in advance of) conscious perception (see endnote 6).

In recent years, there has been a shift on how cognitive psychology evaluates the plausibility of not consciously represented processes. Research on subliminal perception in the early 1950s and 1960s failed because of the persistent challenge to prove the existence of its subject matter beyond any doubt (see, e.g., Eriksen, 1956; Neisser, 1967). By now, the assumption of nonconscious cognitive processes looks almost self-evident. In many models of information flow, conscious representation is banished to a small box at the far right end which is not reached until processing has been completed.

Why shouldn't it be possible to elicit a motor response without consciousness? This possibility seems to meet reservations similar to those that the hypothesis of subliminal perception had to face two decades ago. Then as nowadays the reason might have been a prejudice based on phenomenology: we perceive ourselves as masters of voluntary action and conclude that the latter must be initiated by a consciously represented 'Fiat!' I held this view earlier, overlooking the possibility that the ability to consciously *inhibit* a response does not necessarily imply that it is consciously *triggered*. Doubtlessly, the response in a simple RT experiment is not 'automatic' in the sense that it can be elicited solely by the appearance of the stimulus and independent of the consciously represented action plan. But it is not necessary that everything that is involved in carrying out an action plan has to be consciously controlled (see endnote 7).

A further, neurophysiological aspect should not be disregarded. Visual stimuli can be responded to if they are not consciously perceived, due to neurological damages (e.g., 'blindsight', Perenin & Jeannerod, 1978; Weiskrantz, Cowey, & Passingham, 1977; Weiskrantz, Warrington, Sanders, & Marshall, 1974).

Endnotes

1. This text was originally published in German as an Internal Report of the University of Bochum, Germany in 1982: Neumann, O. (1982). *Experimente zum Fehrer-Raab-Effekt und das "Wetterwart"- Modell der visuellen Maskierung*. [Experiments on the Fehrer–Raab effect and the "Weather Station" Model of visual masking.] Report No. 24/1982, Department of Psychology at the

Ruhr-University of Bochum, Cognitive Psychology Unit. The Weather Station Model has since then been used to explain a variety of spatio-temporal phenomena or illusions such as the Fröhlich effect, the tandem effect, and pre-dating in tapping. In the Fröhlich effect, observers mislocate the first position of a moving stimulus in direction of its movement (Carbone, 2006; Müsseler & Aschersleben, 1998). In the tandem effect, observers perceive two moving bars simultaneously through a slit although they never appear simultaneously (Müsseler & Neumann, 1992). Both phenomena can be explained by the same interplay of updating of a spatial map and attentional allocation that is studied in the present paper. Also, research into the pre-dating of the mask continues ("Perceptual Latency Priming", PLP). Pre-dating can, for instance, also be found when observers tap in synchrony with the onset of a mask that is preceded by a masked test stimulus (Aschersleben, 1999a), and it is dependent on the current intentions of observers, that is, the allocation of attention is top-down contingent (Scharlau & Ansorge, 2003). In this context, the Weather Station model has been renamed the Asynchronous Updating Model (AUM; see Scharlau & Neumann, 2003a, b; see also Scharlau & Horstmann, 2006).

Talis Bachmann has kindly provided the opportunity to make the paper available to a broader scientific community by publishing it in the present special issue of *Psychological Research* together with the companion paper (Neumann & Scharlau, this volume). Heike Hartwig-Jakobs and Ingrid Scharlau translated the manuscript. Ingrid Scharlau also shortened it considerably and provided the endnotes. Because of the editorial work, she now appears as a co-author.

2. The replication mentioned below in endnote 3 used higher intensities (approximately 40 cd/m^2), and also, due to technical restrictions of the PC, a longer test stimulus duration of 6 ms. However, as Scharlau and Neumann (2003b) have shown, test stimulus duration has only a minimal effect (2 ms in that study) on the pre-dating or shift. This and similar studies (Scharlau & Ansorge, 2003; Scharlau & Horstmann, 2006; Scharlau & Neumann, 2003a) have also demonstrated a temporal shift for dark stimuli on a light background and for coloured stimuli on a dark background.

3. Technical reasons—the use of a three-channel tachistoscope—made it necessary to present the standard stimulus always to the left and the test-mask sequence always to the right of fixation. This involves a possible bias effect: observers might, for whatever reason, have reported the right stimulus to be the first one if uncertain. If the presence of a masked test stimulus increased uncertainty, then this might have enhanced such a bias and thereby artificially caused a shift of the psychometric function. To refute this criticism, we replicated the experiment with variable locations of the stimuli. In one session (original task), the locations were the same as in the original experiment. In the other session (non-original task), the locations of the test-mask sequence and the standard were varied. In different blocks, the test-mask sequence appeared in either of the four quadrants of the screen (factor *location of test-mask sequence*). Within a block, the standard stimulus appeared either in the diagonally, the vertically, or the horizontally opposite quadrant (factor *relative standard location)*. Also, we used baseline conditions in which the 'mask' was not preceded by a test stimulus and compared them to conditions with test stimulus (factor *presence of test stimulus)*. In the following, we report the results of two separate ANOVAs, one including the factors relative standard location and presence of test stimulus, the others including the factors location of test-mask-sequence and presence of test stimulus. (It would have been desirous to include all three factors in one ANOVA, but unfortunately, this left only few repetitions in each condition, making computation of the parameters of the psychometric distributions difficult.)

We found a shift in both the original and the non-original task. A two-level ANOVA of points of subjective simultaneity (PSS), derived from the psychometric distributions by logit analysis (Finney, 1971) and averaged across the spatial factors relative standard location and location of test-mask sequence, revealed an effect of test presence ($F[1, 23] = 542.41$, $P < 0.0001$), an effect of session ($F[1, 23] = 10.08$, $P < 0.05$), and an interaction of these factors ($F[1, 23] = 5.29$, $P < 0.05$).

In the non-original task with variable standard location, the observers had a consistent bias in favour of the standard stimulus (PSS deviated from zero even in the condition without test stimulus, all ts[23] > 7.9; all Ps < 0.0001). Interestingly, no such bias was observed in the replication of the original task ($t[23] < 1$ for the baseline condition and $t[23] = 21.67$, $P < 0.0001$ in the condition with test stimulus). In the non-original task, relative standard location had a significant influence on PSS ($F[1, 23] = 13.05$, $P < 0.001$) which interacted with the presence of the test stimulus ($F[1, 23] = 4.8$, $P < 0.05$). Yet, the shift was present for all three relative locations of the standard stimulus, horizontally, vertically, and diagonally (all ts[23] > 12.73, all Ps < 0.0001). Also, the—blockwise varied—location of the test-mask-sequence had an influence on PSS ($F[3, 23] = 2.84$, $P < 0.05$), which was due to a difference of 6 ms between the locations right/top and right/bottom (Bonferroni post-hoc comparisons, $P < 0.05$). Again, however, the shift was significant in all of the conditions (all ts[23] > 9.27, all Ps < 0.0001).

To summarize, although there were numerically small biases and location effects, the main finding was robust in all conditions: with a test-mask SOA of 78 ms, the presence of the test stimulus shifted the psychometric distribution by 45–53 ms, that is, it pre-dated the perception of the mask by about 50 ms. This is corroborated by the finding of a shift of the psychometric distributions in numerous studies in which the location of both the test-mask sequence and standard stimulus was unpredictable (e.g., Scharlau & Neumann, 2003a, b).

4. The task was to report whether the mask had an inner contour independently of whether or not it was

seen as being preceded by the test stimulus. Sometimes observers reported seeing first a disk and then the mask with an inner contour ("fried egg"), though usually no inner contour was reported at SOAs where there was temporal resolution (see Fig. 2).

5. This finding inspired research into temporal dissociations between RT and judgment data. Why RT and judgment data diverge is a question still under debate (for summaries see Aschersleben, 1999b; Jakowski, 1999; see also Neumann, Esselmann, & Klotz, 1993; Steglich & Neumann, 2000).

6. This mode of processing has later been termed Direct Parameter Specification (Neumann, 1990).

7. In parallel to research on Perceptual Latency Priming, this hypothesis has fostered a broad research tradition. The possibility of responding to masked stimuli has been demonstrated in numerous studies (e.g., Ansorge & Heumann, 2006; Breitmeyer, Ogmen, & Chen, 2004; Eimer & Schlaghecken, 2003; Jakowski, Skalska, & Verleger, 2003; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Lingnau & Vorberg, 2005; Lleras & Enns, 2004; Schlaghecken & Sisman, 2005; Skalska, Jakowski, & van der Lubbe, 2006; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Yet, many of these studies have shown that responding to nonconscious stimuli requires a (consciously formed) intention (see, e.g., Ansorge & Neumann, 2005; Klotz & Neumann, 1999).

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