THE DOTS WITHIN THE FENCE: PROTECTION OF VISIBLE PERSISTENCE BY SURROUNDING STIMULI*

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In the experiments reported here, visible persistence is investigated by presenting two parts of one stimulus temporally separated and recording performance at different temporal intervals. It has been proposed by Di Lollo et al. that an important factor limiting visible persistence is inhibition, i.e. the memory trace of the first part is attenuated by the second part of the stimulus. In order to test models of inhibitory interaction more concisely, in the present experimental paradigm an additional condition is introduced where a masking grid is presented on different temporal locations between the two parts of the stimulus. The results of two observers are reported and discussed with respect to models of inhibitory interaction. Two alternative explanations (shifts in attention and apparent motion) are also discussed and rejected on empirical and theoretical grounds.

Key words: Visible persistence, temporal integration, lateral masking, backward masking, inhibition, disinhibition

INTRODUCTION

It is a well known phenomenon that visual perception does not cease immediately after the offset of stimulation, but — dependent on several conditions — might continue for some period. Various methods have been proposed to study this phenomenon (for a review, see Coltheart, 1980); among them some which measure directly the perceived duration of stimulation, and some others which provide indirect estimates of visible persistence by setting up a task where temporally separated parts of a stimulus must be integrated in order to solve the task.

Among these indirect methods, one task frequently being used for the study of visible persistence (e.g. Eriksen & Collin, 1967; Di Lollo, 1980; Di Lollo & Hogben, 1987) requires the synthesis of a pattern whose parts are displayed separately in rapid succession. The display consists of a 5 x 5 square matrix of dots. One of the dots, chosen at random on each trial, is suppressed, and the observer's task is to indicate the location of the missing dot. For the study of visible persistence, the 24 dots of the incomplete matrix are displayed in two successive frames of 12 dots each chosen at random and differently on every trial. Presented separately, each frame appears as a pattern of 12 irregularly distributed dots; however, when shown in rapid succession, the two frames appear as a 5 x 5 matrix of dots with the missing one easily identifiable.

When separating the two frames by

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a variable time interval (interstimulus interval, ISI) during which no other stimulation appears, integration of the two frames is progressively impaired (see, e.g. Di Lollo & Hogben, 1974), from which it can be inferred that visible persistence decreases with increasing ISI. This finding is compatible with the view that visible persistence, as measured by the present task, is based upon some kind of sensory store (Sperling, 1960) or iconic memory (Neisser, 1967) whose contents decay rapidly after stimulus termination. Closer examination, however, questioned that view by demonstrating that the more crucial variable than ISI is the stimulus onset asynchrony (SOA) between the two frames (Di Lollo, 1977, 1980): For a given ISI, the longer the duration of the first frame, the shorter is its subsequent visible persistence. This finding, supported by several studies (summarized and termed „inverse duration effect“ by Coltheart, 1980) led to the proposal that visible persistence is the outcome of visual information processing activity initiated by and time-locked to the onset of the inducing stimulus (Di Lollo, 1977, 1980).

A further elaboration of the factors related to visible persistence was provided by Di Lollo & Hogben (1987). They demonstrated that (1) decreasing the distance between adjacent dots in the display, and (2) increasing the brightness of the stimuli (known as the „inverse intensity effect“ by Coltheart, 1980) both factors reduce visible persistence. Moreover Di Lollo & Hogben were able to provide a coherent theoretical framework capable of explaining these effects based on the theory of inhibitory interaction by Breitmeyer & Ganz (1976). Briefly summarized, it is assumed that a stimulus activates two different kinds of neural pathways or channels: a transient channel which has short latency and responds optimally to low spatial and high temporal frequency, and a sustained channel which has a longer latency and responds to high spatial and low temporal frequencies. A wide range of masking phenomena can be explained by assuming that a transient response inhibits ongoing sustained activity in adjacent areas.

With respect to the visible persistence task, Di Lollo & Hogben (1987) state as a main assumption that activation of transient channels produces some activity which is briefer and has a shorter latency than the activity in the corresponding sustained channels. If two adjacent stimuli are displayed successively at an appropriate time interval, the fast transient activity produced by the second stimulus will inhibit the slow sustained activity, i.e. the visible persistence, of the first. For a short SOA (of, e.g., 20 msec), little or no inhibition should be observed, because the transient activity of the second frame had subsided before the onset of the sustained activity of the first frame, thus enabling integration of the sustained activities of the two frames. However, at a longer SOA (e.g., 50 msec) the sustained activity of the first frame has already been built up before the arrival of the transient activity of the second frame by which it will be disrupted, leaving little sustained activity to be integrated with that of the second frame. Di Lollo & Hogben (1987) predicted that both closer spacing and higher luminance should increase the amount of inhibition and therefore decrease performance within a certain spatio-temporal range, which was confirmed by their experiments.

Since models of inhibitory interaction seem to be most successful in explaining various experimental effects, our intention was to investigate their predictions in a somewhat more complex setting, by introducting and additional masking stimulus, i.e. a line grid consisting of 25 adjacent squares surrounding the dots in equidistance. Since there is now a series of three consecutive stimuli more complex interactions could be expected in the sense of disinhibition (Hartline & Ratliff, 1957; Robinson, 1966; Dember & Purcell, 1967; Mayzner, 1970); i.e. the adjacent and consecutive stimuli might act to inhibit the mask and thereby decrease the ability of the mask to inhibit the target. As Stoper & Banffy (1977) have demonstrated, a neighboring stimulus indeed reduces metacontrast, particularly if the target is an element of a larger configuration (Werner, 1935) as it is the case with the dot matrix.

In an earlier experiment Groner, Groner, Bischof & Di Lollo (submitted) explored this situation by presenting a masking grid simultaneously with the first frame as compared with two control conditions: one presenting no grid at all, and the other one displaying the grid simultaneously with the second frame. The present experiment extends the conditions under investigation by varying systemically the temporal presentation of the masking grid over the whole ISI. This experimental manipulation should show, compared with the no-grid (control) condition, at which spatio-temporal locations the additional inhibitory and disinhibitory activity of the masking grid occurs.

EXPERIMENT

SUBJECTS. Two of the authors served as observers. Both of them had normal vision.

VISUAL DISPLAY. The stimuli were displayed on a Hewlett-Packard 1333A oscilloscope equipped with P15 phosphor. At the viewing distance of 57 cm, set by a head-rest, the dot-matrix — as outlined in the previous section — subtended a visual angle of 2.0 deg.

The dot-matrix was displayed in two successive flashes of 12 dots each. The 12 dots in each frame were chosen randomly (without replacement) on each trial from the 25-dot pool. Thus, the location of the missing dot varied randomly from trial to trial but was balanced over all trials. Each frame was displayed for 20 msec at an intensity of 64 cd/m^2.

The masking grid consisted of a large surrounding square, subtending a visual angle of 2.5 x 2.5 deg, being divided into 25 small squares which, when superimposed, surrounded the dots in a distance of 15'. The luminance of the grid was set to 37 cd/m^2. The background luminance was less than 1 cd/m^2.

DESIGN AND PROCEDURE. The observers sat in a dimly-illuminated room and viewed the displav binocularly with natural pupils. Four fixation points of low intensity defined a 1-deg square area in the centre of the display. The observers initiated each display by pushing a hand held button, upon which the first 12 dots were displayed for 20 msec. Next, there was an ISI of either 0, 20, 40, 60, 80, or 120 msec to be filled by the presentation of the masking grid at a variable temporal delay (MOA, see below). Finallv, the remaining 12 dots were displayed for 20 msec. The observer then identified the location of the missing dot (guessing if not sure) by encoding its matrix coordinates in a 5-button response box.

Figure 1 gives an illustration of the time course of events within an experimental trial. The relevant condition of this experiment was the presentation of the masking grid at various

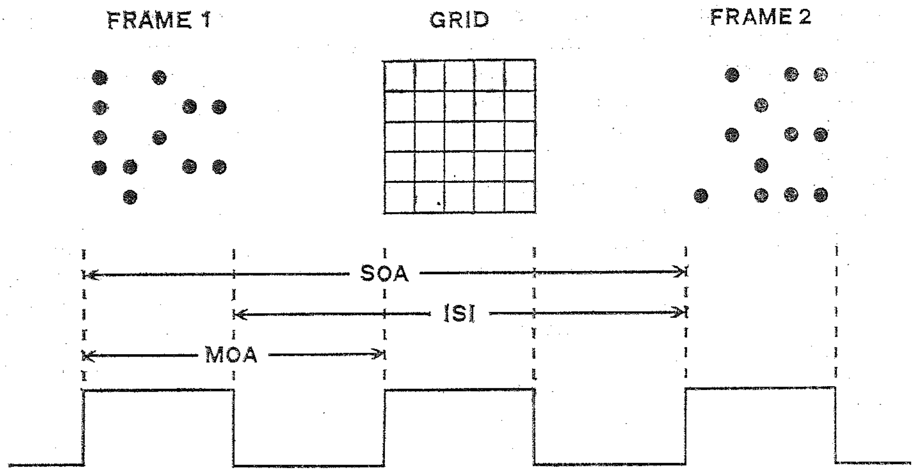

Fig. 1. Temporal sequence of events in the visible persistence paradigm with masking grid. In the present example, 40 msec after onset of the first frame, the grid is presented for 20 msec. With on-times of 20 msec for frame 1, grid and frame 2, SOA is 80 msec, MOA 40 msec and ISI 60 msec. The correct response of the observer would be : the missing dot is in the second row of the second column.

delay times after the onset of the first frame. A masking onset asynchrony (MOA, defined as the time interval between the first frame and the mask), of 0 msec was realized by presenting the grid simultaneously with the first frame. Five additional conditions were realized by MOAs of 20, 40, 60, 80, or 120 msec, respectively. The session under the condition of MOA = 20 comprised 125 trials (25 replications of 5 SOAs); because an ISI of 0 is here not defined due to the onset of the grid at this time interval. In an analogous way, the number of ISIs, and consequently the number of trials per session, decreased for each following condition, down to 25 trials in MOA = 120. In addition, one more condition (MOA = SOA) was realized by presenting the grid simultaneously with the second frame.

An experimental session consisted of 25—150 randomly ordered trials, their number being dependent on the condition. The trials occurred in a different random order in each session, with the same condition prevailing within a single session. A session was completed within about 4—15 min, dependent on the condition. After a „warm up“ of three sessions which were not analysed, the sessions followed in a random order. For each observer and condition, the sessions were replicated four times, yielding a total of 100 observations at each SOA.

RESULTS AND DISCUSSION

Figures 2 and 3 show the percentage of correct responses made by the two observes under all MOA conditions at each of the six durations of the ISI. For reasons of convenience SOAs are drawn instead of ISIs in Figure 2,

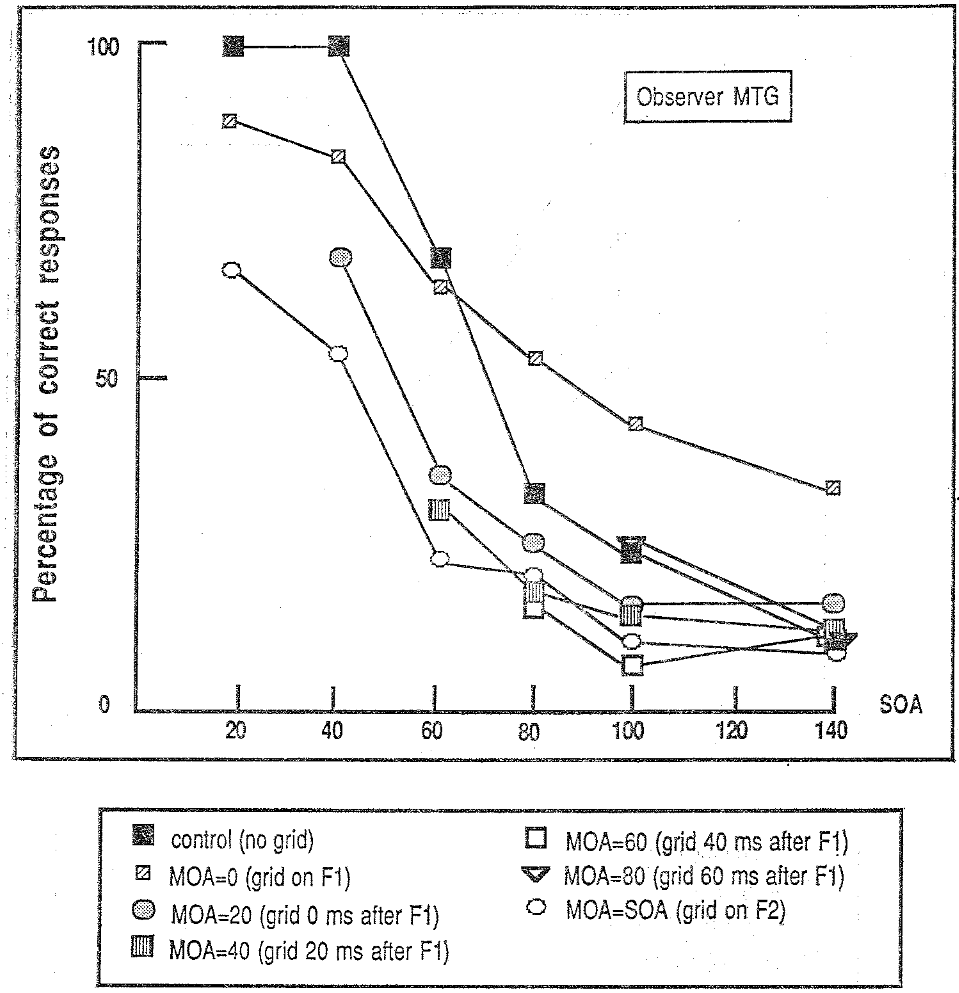

Fig. 2. Percentage of correct responses of observer MTG under different SOAs (abscissa) and different MOAs (inside the Figure).

with the simple relation: SOA = ISI + duration of the first frame (see also Figure 1).

For simplicity of argumentation, the following discussion of the results will proceed in three steps: first, the control (= no grid) condition will be compared with the MOA = 0 (grid on F1) condition, then the with-grid conditions are compared with each other, and finally these results are put together within a common interpretation.

Comparing the conditions of no grid with MOA = 0, it can be seen in Figures 2 and 3 that the accuracy of performance was high at short SOAs, but deteriorated as the duration of the

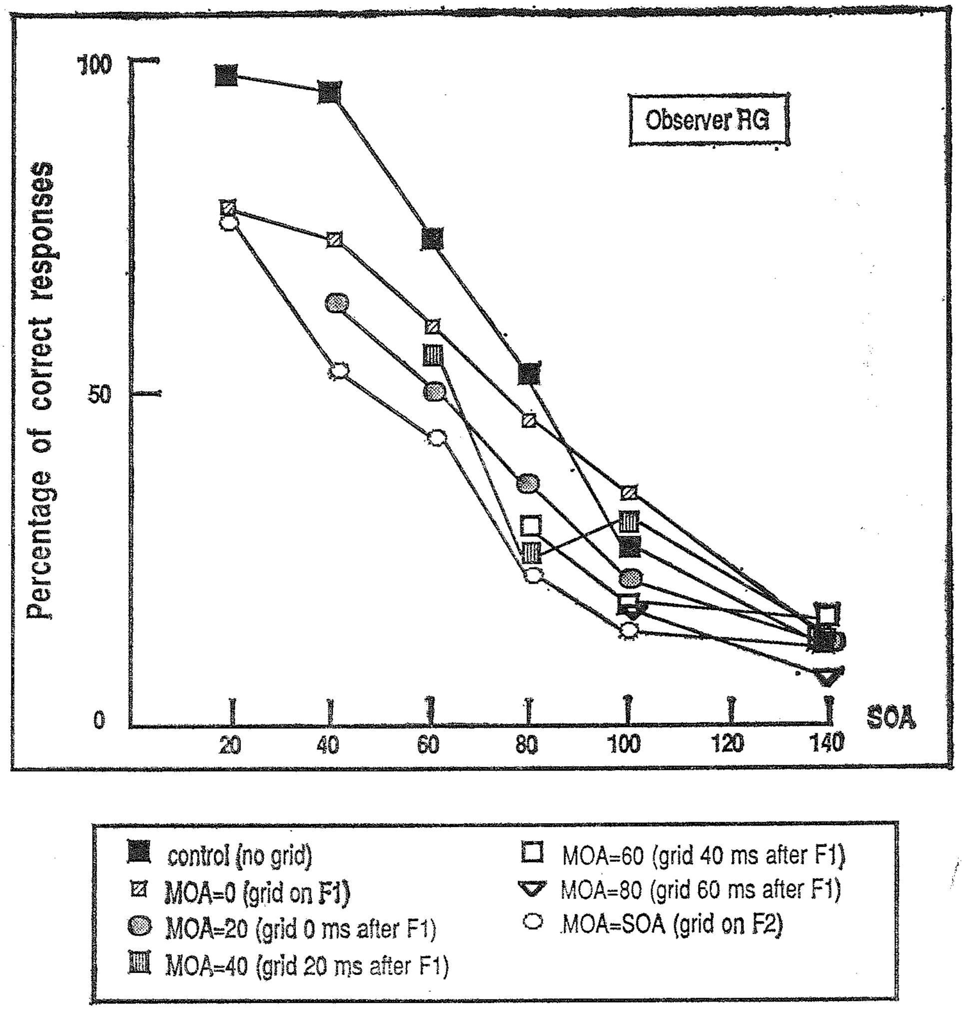

Fig. 3. Percentage of correct responses of observer RG under different SOAs (abscissa) and different MOAs (inside the Figure).

SOA increased. Both observers show also an identical interaction between the experimental conditions and SOA: At brief SOAs, the accuracy of performance is higher under the control condition without the grid, whereas at longer SOAs performance of the experimental condition with a grid on the first frame becomes increasingly superior compared with the control condition.

The different results under the two conditions can be accounted for by mechanisms of inhibition: At short SOAs, the lower performance with the grid was caused by processes of lateral masking, i.e. the reduction of the probability of correctly identifiyng a target when it is surrounded by other items (Mackworth, 1965; Bouma, 1970; Wolford & Chambers, 1984). If the SOA becomes longer, mechanisms of disinhibition begin to work (Stoper & Banffy, 1977) where the grid acts like a fenee or barrier, protecting the dots of the first frame from inhibition initiated by the second frame.

Comparing next the different MOA conditions, a continuous decrease of performance can be observed with increasing MOA. Performance is reduced more, if the masking grid is presented at a later moment within a given ISI. This finding can be explained by combining the assumption of a decaying trace of the first frame (sustained response) with the assumption of an inhibitory (transient) response initiated by the masking grid (Breitmeyer & Ganz, 1976). In addition to this main effect of the MOA conditions, there is also a small tendency towards a statistical interaction between MOA and SOA, caused by the condition of MOA = 40. However, since the pattern of interaction is not identical within the two observers, no interpretation will be attempted.

Summarizing the results of the experiment, there is a relatively regular decay of the performance curves over all with-grid conditions following a systematic pattern: the longer the lag of the masking grid, the more detrimental the effect it has on visible persistence. However, compared with the no-grid control condition, there is an impairment of performance on short SOAs (less than 60 or 80 ms) and an improvement on longer SOAs, up to 140 ms where all curves reach chance level. This phenomenon of „protection of visible persistence" is the most non-trivial result of the present experiment, and it has been explained by mechanisms of disinhibition.

The decrease of performnace at short SOAs can be accounted for by processes of lateral masking. It is consistent with the results of a study by Wolford & Chambers (1984) who estimated the extent of contour interaction to be 0.04 — 0.12 deg for targets at the center of the fovea, and 0.5 — 1 deg for targets 5 deg in the periphery. Therefore, in the present experiment, a lateral masking effect can be expected for the peripheral dots. It follows for the present conditions that the 16 dots in the periphery of the matrix are expected to be masked most, compared to the remaining 9 dots in the center. This prediction was supported by Groner, Groner, Bischof & Di Lolo (submitted) by showing that in the condition with grid on the first frame the peripheral dots are indeed affected more by the introduction of a grid than the central dots.

As a next step, the present qualitative formulation of the model should be parameterized by modeling the spatio-temporal interactions in a quantitative way. An experimental series with similar intention, and also thematically relevant to such an enterprise, has been performed by van der Wildt & Vrolijk (1981) investigating the propagation of inhibition. These authors proposed that at a retinotopic early stage of visual information processing an inhibitory wave travels with a speed of 3.1 — 4.2 minutes of arc per msec. Since in the present experiment the spatial separation between dots and grid line was 30 min, inhibition is expected to be activated already 7—10 msec after stimulus onset. As a consequence of these results, the temporal spacing of SOA and MOA in future experiments with the grid paradigm should be adjusted according to these predictions.

GENERAL DISCUSSION

Up to this point, the whole theoretical discussion has been focussed entirely on models based on inhibitory interactions. Two alternative positions should also briefly be discussed.

The first position emphasizes processes of the allocation of attention (for a review of relevant research along this line see Groner 1988, or Groner & Groner, in press). From an attentional point of view it could be argued that the presentation of the grid restricted the observers' focus of attention to the central portion of the display ignoring the peripheral dots and therefore producing correspondingly more errors in the with-grid conditions compared to the no-grid control condition. Such a hypothesis, however, has been rejected by Groner et al. (in press) by showing that under the condition of grid-on-F2 (SOA = MOA), which should have an identical effect on the allocation of attention, no preference for the central dots could be found.

A second alternative position assumes that perceived apparent motion between parts of frame 1 and of frame 2 makes it more difficult to integrate the two stimuli. Phenomenally, at short SOAs under both conditions the two sets of dots were seen as a single integrated matrix, and the location of the missing dot could easily be identified. However, at longer SOAs the phenomenal appearance was different under the two experimental conditions. Under the control condition with no grid, parts of the display consisting of single dots or patches of adjacent dots gave a strong impression of apparent motion which made it difficult to impossible to infer the location of the missing dot. Under the experimental condition with grid, the two frames were seen as separate configurations with no associated motion.

One possible explanation of the experimental result would now focus on this motion effect: Performance under the grid condition is better because the grid acts as a barrier, suppressing motion perception. Since apparent motion has almost identical optimal SOAs as metacontrast (Stoper & Banffy, 1977), it would be difficult to decide on this issue by the present experiments. We rather prefer a position which assumes that inhibition is the more basic process, regulating both, metacontrast and apparent motion. Dependent on the spatio-temporal arrangement of the visual scene, parts of successive stimuli are either less accentuated by metacontrast, or combined into an impression of apparent motion. Thus serving both situations, inhibition is one of the most important functions of the visual system whose spatial and temporal properties should be investigated in more detail and which should be brought into a closed parametric model.

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ОГРАНИЧЕННЫЕ ТОЧКИ: ОХРАНА ЗРИТЕЛЬНОЙ УСТОЙЧИВОСТИ ПОСРЕДСТВОМ ОКРУЖАЮЩИХ СТИМУЛОВ

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Резюме

В приведенных экспериментах изучалась зрительная устойчивость так, испытуемым предлагались две части стимула, распределенные во времени, и достижение исследовалось отдельно для каждого отрезка времени. Фон ди Лолло и его сотрудники предлагают торможение как важный фактор, который ограничивает зрительную устойчивость, т. е. след памяти первой части стимула ограничивается второй. Для более точного исследования ограничительного взаимодействия в данную экспериментальную парадигму было включено дополнительное условие, в котором было сеть в виде маскировки между двумя частями стимула в разные отрезки времени. Приводится описание результатов двух испытуемых по отношению к моделям ограничительного взаимодействия. Одновременно рассматриваются две гипотезы (сдвиг внимания и эффект воображаемого движения), и опираясь на эмпирические и теоретические аргументы, авторы отказываются от них.

OHRANIČENÉ BODY: OCHRANA ZRAKOVEJ PERZISTENCIE OKOLITÝMI STIMULAMI

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Súhrn

V predložených experimentoch sa vizuálna perzistencia tak skúmala, že sa prezentovali dve časti podnetu časove oddelené a výkon sa skúmal pre každý interval. Von di Lollo a spolupracovníci navrhli útlm ako dôležitý faktor, ktorý obmedzuje vizuálnu perzistenciu, t. zn. pamäťová stopa prvej podnetovej časti je obmedzená druhou časťou. Aby sa mohol model inhibičného vzájomného pôsobenia presnejšie skúmať, zaviedla sa do tejto experimentálnej paradigmy doplnková podmienka, v ktorej bola prezentovaná sieť ako maskovanie medzi dvomi časťami podnetu v rôznych časových intervaloch. Opisujú sa výsledky dvoch probandov a diskutujú sa vzhľadom na modely inhibičnej interakcie. Súčasne sa diskutujú dve hypotézy (posunutie pozornosti a efekt zdanlivého pohybu), ktoré sa odmietajú na základe empirických a teoretických argumentov.