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# EFFECTS OF SEQUENTIAL AND SIMULTANEOUS PRESENTATIONS OF INFORMATION

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# Abstract

In decision making different presentations of the relevant data may influence how quickly a correct decision is made. One way in which presentations of data can vary is whether the relevant data are available simultaneously or sequentially to the decision maker.

Field studies and results obtained in the area of control room design indicate that simultaneous presentations lead to faster decisions. Since computers are increasingly being used to provide data to decision makers, and computer presentations of data on VDU:s tend to be sequential, these indications needed to be investigated further.

An analysis of the two forms of presentation provided six possible explanations of the observed superiority of simultaneous presentations. These were tested in a series of three experiments.

The results show that simultaneous presentations do lead to substantially shorter decision times and that this effect doesn't diminish with practice even when experienced computer users are used as subjects. Of the six possible explanations only one cannot be rejected. This explanation states that the effect is due to an interference in working memory between information used for making the decision and information used for controlling the human-computer interface. The implications of these findings are discussed.

# Introduction

In a traditional, "paper-aided", decision making situation it is possible, and quite common, to order the documents of interest in such a way that they can be seen simultaneously, for instance by spreading them over the entire desktop. Several authors, for instance (Bolt, 1984; Allard, Lind, Sandblad & Schneider 1984; Schneider, Lind & Sandblad 1984; Sypplie, 1986; Lind, Petterson, Sandblad & Schneider 1988), have argued that, for different reasons, a simultaneous presentation of data, as compared to a sequential one, ought to be beneficiary to a human user of the data. In several field studies (unpublished data) researchers from our group have found that decision making indeed in some instances seems to be slower in computerized situations than in paper-based situations and that this could in part be caused by the enforced sequential presentation of data present only in the computerized situation.

The issue of sequential versus simultaneous presentations of data has received some attention by authors considering the human factors issues of control room design. The discussion is indecisive. One view is that the sequential presentation of process data on a VDU is favourable to the simultaneous data presentation of wall mounted control panels found in older control rooms. The reasoning behind this view is "that the operator in those systems *(wall based panels*) is not able to collect all the relevant information 'at once', but instead has to 'sample'. To do so, it would be easier for him to sample from one position, via the VDU, the information he needs and to command the system which information he wants to be displayed" (Dallimonti, 1973 as referenced by Kragt, 1984 p. 927). An opposite view is offered by Sypplie (1986) where the author argues that simultaneous data presentations are superior to sequential ones. He refers in particular to "several tests ...... showed that up to a certain quantity of information, parallel reception ..... permits faster processing" (Sypplie, 1986 p. 41).

The only well documented experimental study in the literature is reported by Kragt (1984) and is concerned with the performance of human operators in a control room given that the process-data are, among other things, presented simultaneously or sequentially. The result of the study is that: "Sequential information-presentation proved to be inferior to a system based on simultaneous information-presentation both in performance and ratings" (Kragt, 1984 p. 927). This study is interesting since it finds an effect in a more controlled laboratory setting, but it is insufficient in a more general context of computer usage for at least two reasons: Firstly, it does not shed any light on why a simultaneous presentation of data is better than a sequential one and, secondly, results obtained with operators controlling a dynamic process are not necessarily valid in other decision making situations.

If the superiority of simultaneous presentations of data over sequential presentations found by Kragt and hinted at by anecdotal evidence and our own field studies, could be explained in terms of fundamental cognitive or perceptual mechanisms, much would be gained. There would, for instance, be a better base for knowing in what situations this effect applies and also for knowing if this just is a temporary effect of present day technology or if it is a fundamental issue of information-system design that is relatively independent of the technology itself.

The aims of the experiments performed were consequently:

1, To see if the superiority of simultaneous data-presentations over sequential data-presentations could be found in a controlled laboratory setting with tasks modelling decision making situations found in office environments.

2, If the above mentioned superiority, in the following referred to as "the effect", is found, to find the explanations of it in terms of fundamental human cognitive or perceptual abilities.

## A note on decision making

Decision making is the essence of many jobs especially in the office domain. The introduction of computer systems as an aid for workers today usually is a question of providing data to the worker in a faster, better and less costly way than before.

Consequently, the introduction of a computer system can usually be understood as a change of medium for the data needed for decisions rather than as an aid for the decision making per se (i.e. automated algorithms, expert systems etc.). This will no doubt continue to be the case for quite some time to come[1] and this is the situation the experiments are modelled from: A human decision maker accessing relevant data through a computer system.

Data are usually accessed through a computer system either by chosing pre-determined forms which in turn access a database system or by typing queries directly to the database system. Our field studies show (unpublished data) that the time span used for most decisions in office work is between a few seconds and a minute. This means that users prefer to scan forms to find the relevant information. The time it takes to mentally form logically correct queries in some query language (plus the time it takes to specify them, usually by typing) is much longer than letting your vision scan a few screens for the relevant information. Scanning also has the advantage of facilitating the discovery of other interesting, in relation to the decision at hand, data not originally thought of by the decision maker.

The studies described in this paper subsequently model the situation in which a decision maker scans forms on a computer screen in search of data relevant to the decision.

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[1]There are at least two reasons for this belief: Firstly, how to make good decisions is, at least today, difficult to formally describe in many cases and, secondly, many decisions require data only some of which are available through the computer system. One important class of data usually not stored in computer systems are data which are accurate only for a short period of time. Until the time comes when computer systems have perceptual capabilities of their own (which is the case already in process control!) such varying data are, for economical reasons, known to humans only. When the decision is to be made and such data are important it is much faster for the human to access the data stored in the computer system, in her mind add the data known to her, and make the decision than to transmit all the data known only to her to the computer and let it make the decision.

# Possible explanations of the effect

When considering facts and findings concerning human cognitive and perceptual functioning, and what is known about human-computer interaction, it is easy to find at least six possible explanations to why the superiority of a simultaneous data-presentation over a sequential one has been observed. They are:

1, The effect does not exist per se but is a result of other factors present in the situations studied.

2, Differences in the amount of previous experiences with sequential and simultaneous presentations of data.

3, The performance in the sequential condition is slower because of information-decay in working memory due to long system response times.

4, More data need to be concurrently active in working memory in the sequential condition than in the simultaneous one.

5, Differences in the possibilities to detect and utilize visual patterns in the data in the two conditions.

6, The ability of humans to code things in terms of their spatial location is impaired in the sequential condition.

These possible explanations are elaborated in the following.

### 1, The effect does not exist per se but is a result of other factors present in the situations studied

In the above mentioned field studies the presentations differed in other aspects than the sequential-simultaneous aspect. For instance did the situations with a sequential presentation of the data involve a computer system while the ones with a simultaneous presentation did not. The effect of these other aspects were judged unimportant by the time the field studies were made, but need of course be removed or controlled. Also in the study by Kragt mentioned above, there were uncontrolled differences between the conditions apart from the sequential-simultaneous aspect.

### 2, Differences in the amount of previous experiences with sequential and simultaneous presentations of data

Most people have a much longer experience with using data recorded on paper, and handling sheets of paper, than in using data available through a computer. Since most paper-based situations resemble a simultaneous presentation of data[2] and most computer based situations resemble a sequential presentation of data[3] this means that a randomly chosen population will have more experience with simultaneous data-presentations than with sequential ones.

### 3, Information-decay in working memory because of long system response times

It is an obvious idea that if a degraded performance in a sequential situation exist, it is caused, and only caused, by too long a response time on behalf of the system. The reasoning is as follows:

Consider a decision-making situation where data is presented in a window (or on a screen if a traditional VDU is used) and there are more data relevant to the decision than is displayed in the window at any one time. This means there is a need for the decision-maker to change the contents of the window and read the rest of the data before the decision can be made. The time it takes for the computer system to change the contents of the window, if that time is too long, causes some of the data, read from the previous screen and held in working memory, to decay. Such a decay does not occur in the simultaneous situation since the time to shift the fixation of the eyes is negligible in terms of decay in working memory. The decay leads to a need to refresh the contents of working memory more often in the sequential

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[2]A sheet of paper offers approximately 50+ rows of characters and it is often the case that two or more sheets of paper are placed beside one another.

[3]Most screens show 24-32 rows of characters and there are rarely more than one such screen available concurrently running the same program.

situation and hence a slower total performance in that situation than in the simultaneous one.

While definitely worth testing, this reasoning can be doubted as being the complete explanation since some of the computer systems studied by our group have response times of less than half a second (to change the contents of an entire 24 by 80 character screen), and still the difference between sequential and simultaneous presentations of data seemed to be present.

Nevertheless, if the above reasoning is the complete explanation it implies that the observed difference in performance in simultaneous and sequential situations will vanish with improved technology and that it is of marginal theoretical interest, albeit it would be an important factor to consider while designing systems today.

### 4, More data need to be concurrently active in working memory in the sequential situation than in the simultaneous one

This idea hinges on a view of the decision making as consisting of, at least, two concurrent mental tasks - the decision making task and the task which can be described as 'data-control' i.e. the task of getting the desired (by the decision making process) data into view.

These two tasks compete for the limited resources of working memory and if one of them, or both, is resource demanding enough to fill the capacity of working memory, a loss of data in working memory will occur. The lost data must be recovered in some way and this will result in a longer time for the decision maker to reach a correct decision than if this data loss hadn't occured.

In the case of a simultaneous presentation of the data, the data-control process consists of controlling the fixation point of the eyes, while in the sequential case it consists of commanding the computer to display desired data not presently on the screen. It is not an unreasonable idea that the commanding of a computer demands more data to be active in working memory than the controlling of the fixation point of the eyes and that this is the reason why decisions are reached more slowly when data are presented sequentially as compared to simultaneously.

Some theoretical support for the view of command-giving as a resource demanding activity, in terms of active data in working memory, can be found in Norman(1986 pp. 31-62).

### 5, Differences in the possibilities to detect and utilize visual patterns in the data in the two conditions

In the study of visual perception there are numerous examples of how easily and efficiently people discover and utilize meaningful patterns in their environment (see for instance Gibson J.J., 1966 and Gibson E.J., 1969). One inherent property of sequential presentations of data is that possible patterns in the data are defined as spatio-temporal patterns while simultaneous presentations allow the same patterns to be defined as spatial patterns. If spatial patterns are easier to detect and utilize, as compared to spatio-temporal ones, this could account for the superiority of the simultaneous presentations.

### 6, The ability of humans to code things in terms of their spatial location is impaired in the sequential condition

The spatial location of data is a powerful organizing principle and an aid in the recall of the data (see Bolt, 1984 for an overview, also Lovelace & Southall, 1983). A sequential presentation of data often makes it impossible to code the data in terms of their positions since data in a computer system, not presented on the screen, do not reside in any particular place[4] (for a discussion see Miller, 1968). A simultaneous presentation of the data usually (unless the data are being constantly reshuffled) permits spatial coding to take place and this may be the crucial factor causing decision making to be more efficient during this condition.

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[4]It is however quite interesting to note that although data stored on a disk are accesed symbolically by programs and programmers they are in fact retrieved by the hardware in terms of their place on the disk.

# Experiment 1

This study tested three hypotheses:

a, The effect is real and can be found in a controlled laboratory setting.

b, If the effect exists it is entirely due to the strain on working memory caused by the system response time.

c, If the effect exists it is due to the ability of humans to code things in terms of their spatial locations.

These hypotheses are derived from items 1,3 and 6 in the list of possible explanations presented above.

## Method

### The task

As mentioned in the introduction, several field studies have been conducted by our group studying effects of computer usage in working life. A couple of these studies concerned the bookings of patients in a doctors' office. The results indicated that in the world of meetings and agendas the different ways of presenting data is a factor of great importance and therefore this task domain was chosen for the experiment.

The constructed task consisted of scheduling a one hour long meeting where four specific persons should meet. The meeting must be set up during a particular week and the agendas of the four participants for that week were shown to the subjects. In finding a date and time for the meeting the subjects had to adhere to four rules. The first rule stated that a meeting is possible only if at least three of the persons involved had that time available. The other three rules regulated what could and could not be done if three persons had a certain hour available and the fourth did not.

To each week, which constituted a trial, there was one, and only one, hour in which a meeting could be set up without breaking any of the four rules.

## Design

To create a test of the hypothesis that the effect is real, one condition with a simultaneous presentation of the agendas and one condition with a sequential presentation of the agendas had to be constructed where all conceivable extraneous explaining factors were removed. This was done by the use of a workstation, an HP-Apollo DN 3000, with a large, 19", screen having a screen resolution of approx. 75 dpi. On this large screen a one-week page from each one of the four agendas could be shown simultaneously. This is illustrated in fig. 1a. Obviously, a page from only one agenda at a time could also be presented, which constituted the sequential condition. This is illustrated in fig. 1b. The pages were identical whether they were presented sequentially or simultaneously.

In the sequential condition there is a need for the decision maker to command the system which agenda to display. Since the basic issue concerned the time it takes to make a decision it was at the utmost importance that the commands from the decision maker to the system could be given as fast as possible. The work done by Card, Moran & Newell (1983) indicates that one keystroke per command is the fastest. In accordance, each command was assigned to a specific key on the keyboard. The keys used for selecting which agenda to be shown on the screen were adjacent to one-another[5]. Consequently, there was no need for the subject, during the time the decision was made, to move the hand.

[5]The keys "7","8,"9" and "-" on the numerical keyboard were used.

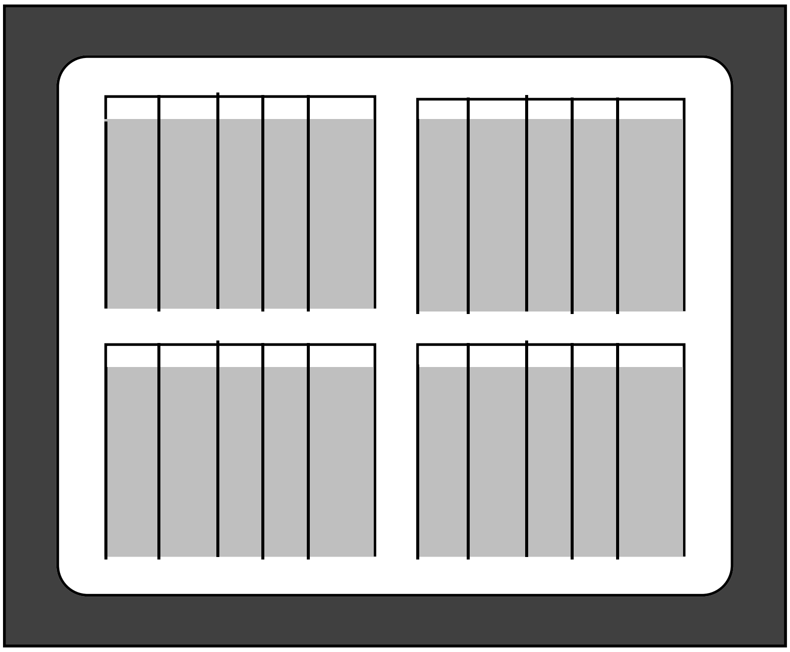

Fig 1a

The simultaneous situation. All the agendas are visible simultaneously on the screen.

The subjects indicated to the system that they had reached a decision by depressing the space-bar on the keyboard (this was true for all conditions). The time elapsed from the start of the trial to this key-press was recorded and used as the primary measure. This means that the time used by the subjects to transmit their decision to the system was not included in this measure. Whenever the space-bar was depressed the agendas of the four people disappeared and a single, empty agenda was displayed. By means of a cursor and a mouse the subjects indicated which hour of the week they had chosen by pointing and clicking at it.

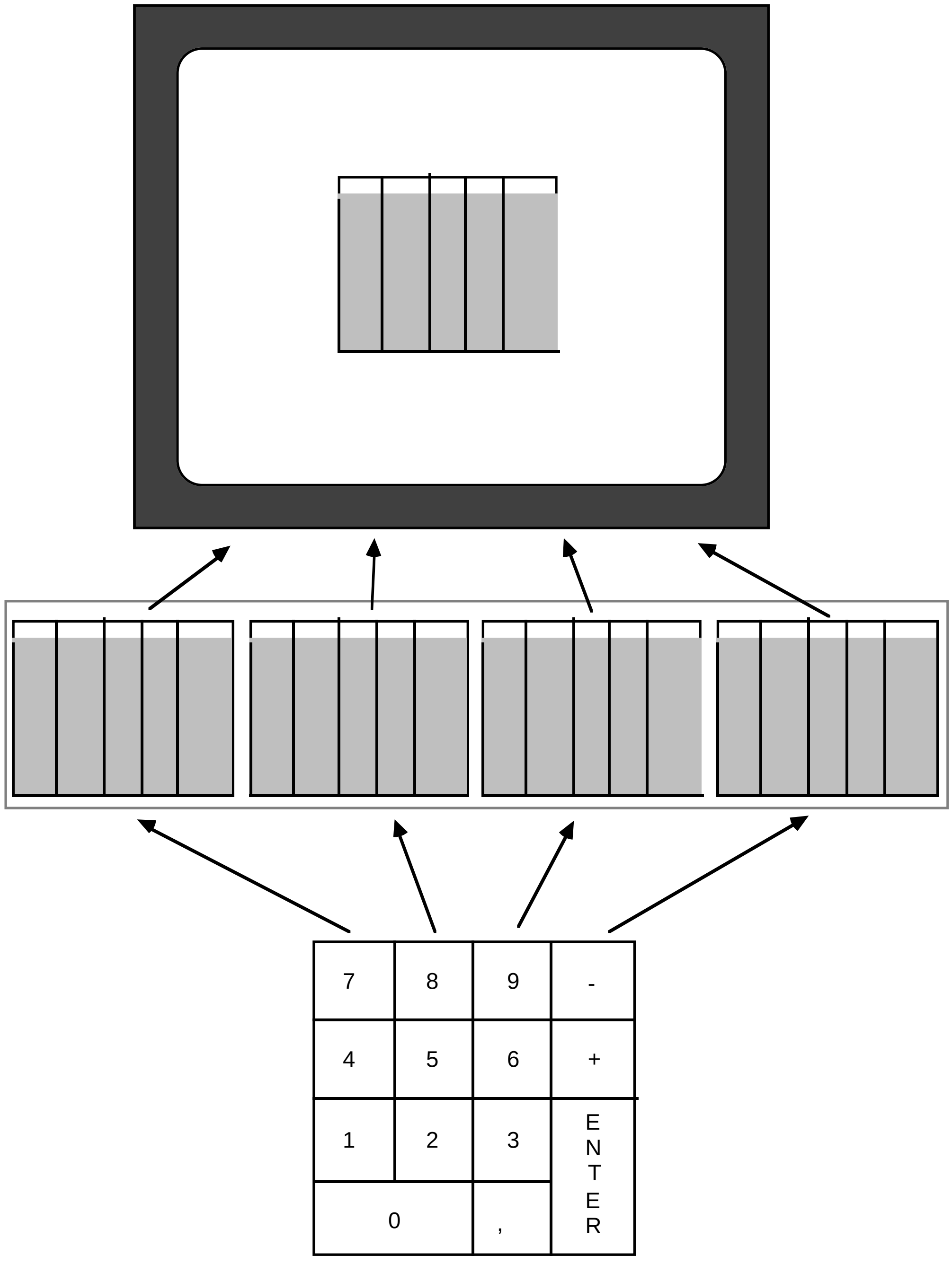


Fig 1b

The sequential situation. Only one agenda at the time is visible on the screen. Each agenda is linked to a specific key on the numeric keyboard. Keys "7","8","9" and "-" were used. The user can view the wanted agenda by pressing the corresponding key.

To eliminate the effects of a possible accuracy for speed trade-off the subjects were instructed to be certain to be right before they indicated to the system that they had reached a decision. Furthermore, if they still gave an incorrect answer, the system returned to the same trial and the previously recorded time was added when they again depressed the space bar. The errors on each trial, if any, were also recorded.

To test the hypothesis that the superiority of a simultaneous presentation ("the effect") is not entirely due to the strain on working memory caused by long system response times, the system was so constructed that the response time (the time from the depressing of a selection key to the next agenda was displayed) never exceeded 0.07 seconds. Such short a time is well within the limits of working memory and should take away the effect given that this hypothesis is correct.

The hypothesis that the effect is due to the ability to code things in terms of their spatial location was tested by letting the agendas either be appearing at the same position throughout the experiment or be appearing at a varying position between each trial. This was treated as one factor ("the position factor") in a factorial experiment and the type of presentation ("the presentation factor") as another. A constant position in the sequential presentation meant that the agenda of a specific person could be associated with a specific key throughout the experiment and a varying position that the mapping between key and person was changed between each trial. A set of four different mappings between position and person was selected. The selection was done in such a way that no two mappings had the same relative internal order.

Pilot studies showed that subjects often favoured a strategy which meant that they started in the upper left corner of the agenda and searched column by column until they reached the lower right corner. A usage of this strategy means that the time to reach a decision will be correlated with the position of the correct hour on the page of the agenda. To prevent this from influencing the results, each block of trials, see below, had approximately the same mix of positions of the correct hours. This was accomplished by randomly assigning correct answers to either the first half of the week or the last half of the week and letting this be a factor in the construction of a block.

Since the effect of the position factor could be dependent on practice it was decided that the subjects should perform more than a few trials. In order to eliminate the effect of the search strategy described above and a possible effect of the different mappings, blocks of eight trials were constructed. Each block consisted of each of the four mappings in conjunction with randomly assigned correct answers in either the left part of the agenda or the right part of the agenda. Three such blocks of eight trials were used in the experiment.

The resulting design was thus a 2x2x3 factorial design with the between-subjects factors being the presentation factor and the position factor. The within-subject factor was consequently blocks of trials. The presentation factor and the position factor formed four groups. Eight subjects were randomly assigned to each of these groups. A random order of the eight trials was determined for each block and given to the first subject. The rest of the subjects in the group were given the trials in a variation determined by the latin-square principle.

### Subjects

Thirtytwo volunteering students, fourteen male and eighteen female, between the age of 17 and 25 served as subjects and were paid 50 SEK for their participation. None of these were experienced computer users.

### Procedure

Each subject received a description of the task and the rules needed to solve it. After being given five minutes to read the material the subject was taken to the computer system and shown how to run it. Through a series of eight trials, identical to all subjects but presented according to the experimental situation the subject was assigned to, the subject practiced the task and the running of the system. During this time they could at any time ask questions about their task or the running of the system. When these eight trials were completed the experiment commenced.

## Results and discussion

The times measured for each trial were converted into a speed measurement - the number of solved trials per minute. This was due both to the fact that a better performance is indicated by a lager number when speed is used and to the better approximation to a normal distribution of the speed measures. (As a check the ANOVA, see below, was carried out both on the untransformed data and the transformed data and these two analyses gave the same result in terms of significance.)

The error data were first examined. They showed that the subjects had followed the instructions closely, there were only occasional error with a grand mean of 1.4 errors per person over the entire 24 trials.

The mean of the speed measures of each cell is shown in fig. 2. An ANOVA was carried out on the speed data. This showed that there were two significant main effects, the 5 % level was chosen, and no interaction effects. The significant main effects were the presentation factor ($F(1,28) = 12.01$, $p < 0.0017$) and blocks of trials ($F(2,56)=20.16$, $p < 0.0001$).

The conclusions are straightforward. The hypothesis that the effect is real cannot be rejected while the two remaining hypotheses receives no support at all in this experiment. As a result the other possible explanations given in the previous list must be considered.

Concerning the position factor there is a possibility that the relative positions of objects are coded extremely fast and that the reshuffling between trials consequently didn't disturb this process. This is also left for further studies to clarify.

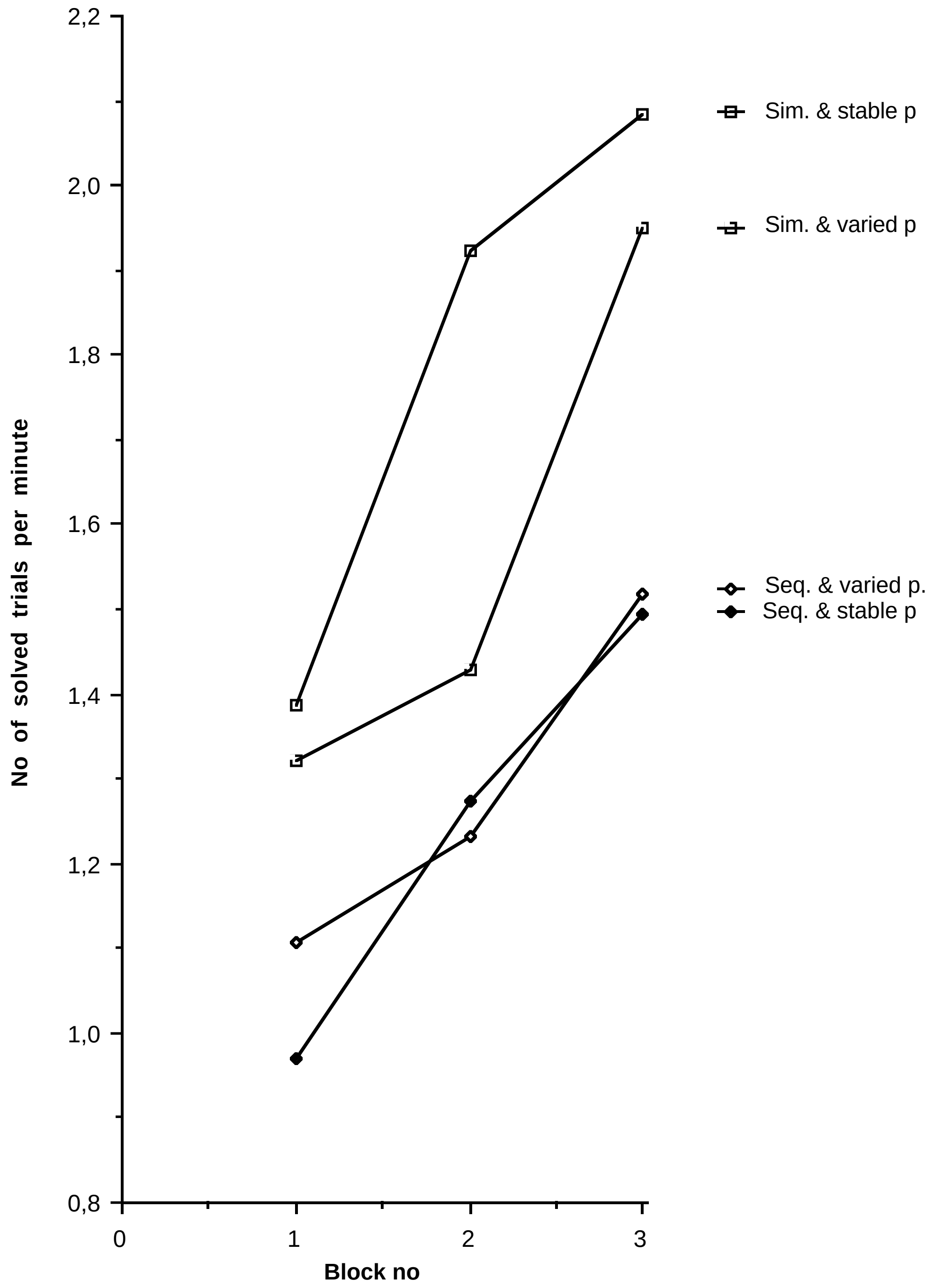
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0
1
2
3
Block no
No of solved trials per minute
Sim. & stable p
Sim. & varied p
Seq. & varied p.
Seq. & stable p

Fig 2

# Experiment 2

This study tested two hypotheses:

a, The effect is real and can be found in a controlled laboratory setting.

b, The effect will disappear with practice.

These hypotheses are derived from items 1 and 2 in the list presented above.

## Method

The same task and the same procedure as in experiment 1 was used.

### Subjects

Since the object of this study was to investigate the effect of a great familiarity with a sequential presentation of data, one of the vehicles to fulfil this object was the use experienced computer users as subjects. The criterion for being an experienced computer user was at least two years of full time work as a programmer or two years of full time study in the computer science department of the university. Sixteen such persons served as subjects, ten male and six female. They were paid 200 SEK each for their participation.

### Design

This experiment was a variation of experiment 1. The position factor was not used and the blocks of trials were increased from 3 to 27 in order to further investigate the effects of practice. The design was thus a 2 x 27 factorial design with the factors "form of presentation" and "block of trials". As in experiment 1 the presentation factor was administered between subjects and blocks of trials within subjects.

### Procedure

As in experiment 1, each subject received a written description of the task and the rules needed to solve it. After being given five minutes to read the material the subject was taken to the computer system and shown how to run the program. Through a series of eight trials, identical to all subjects but presented according to the experimental situation the subject was assigned to, the subject practiced the task and the running of the program. During this time they could at any time ask questions about their task or the system. When these eight trials were completed the experiment commenced.

In order to avoid the effects of fatigue, the first 12 blocks of trials were given on the first occasion and the remaining 15 blocks at another occasion. The interval between the two occasions was between 24 and 48 hours.

## Results and discussion

As in experiment 1, the time measured for each trial was converted into a speed measurement - the number of solved trials per minute. The means of each group, each based on three blocks of trials, are shown in fig 3.

The examination of the error data showed that errors were rare and that the subjects therefore had followed the instruction.

An ANOVA was carried out on the speed data. This showed that both the two main effects and the interaction were significant, as in the previous experiment the 5 % level was chosen. (The "form of presentation" result was $F(1,14)=5.91$, $p<0.0291$, the "block of trials" factor result was $F(26,364)=26.04$, $p<0.0001$ and the interaction result was $F(26,364)=1.86$, $p<0.0072$).

Thus the effect was once again found even with experienced users and, furthermore, the superiority of the simultaneous presentation increases as the subjects use the systems. Of course this interaction may only reflect a constant *ratio* between the two forms of presentation - a constant ratio means an increasing difference as the level increases. The interpretation of this interaction, although interesting, has however little significance for the testing of the hypotheses.

The overall results simply show that the hypothesis that the effect is real cannot be rejected and that there is a strong support in the obtained data in favour of rejecting the hypothesis that the effect disappear with practice.

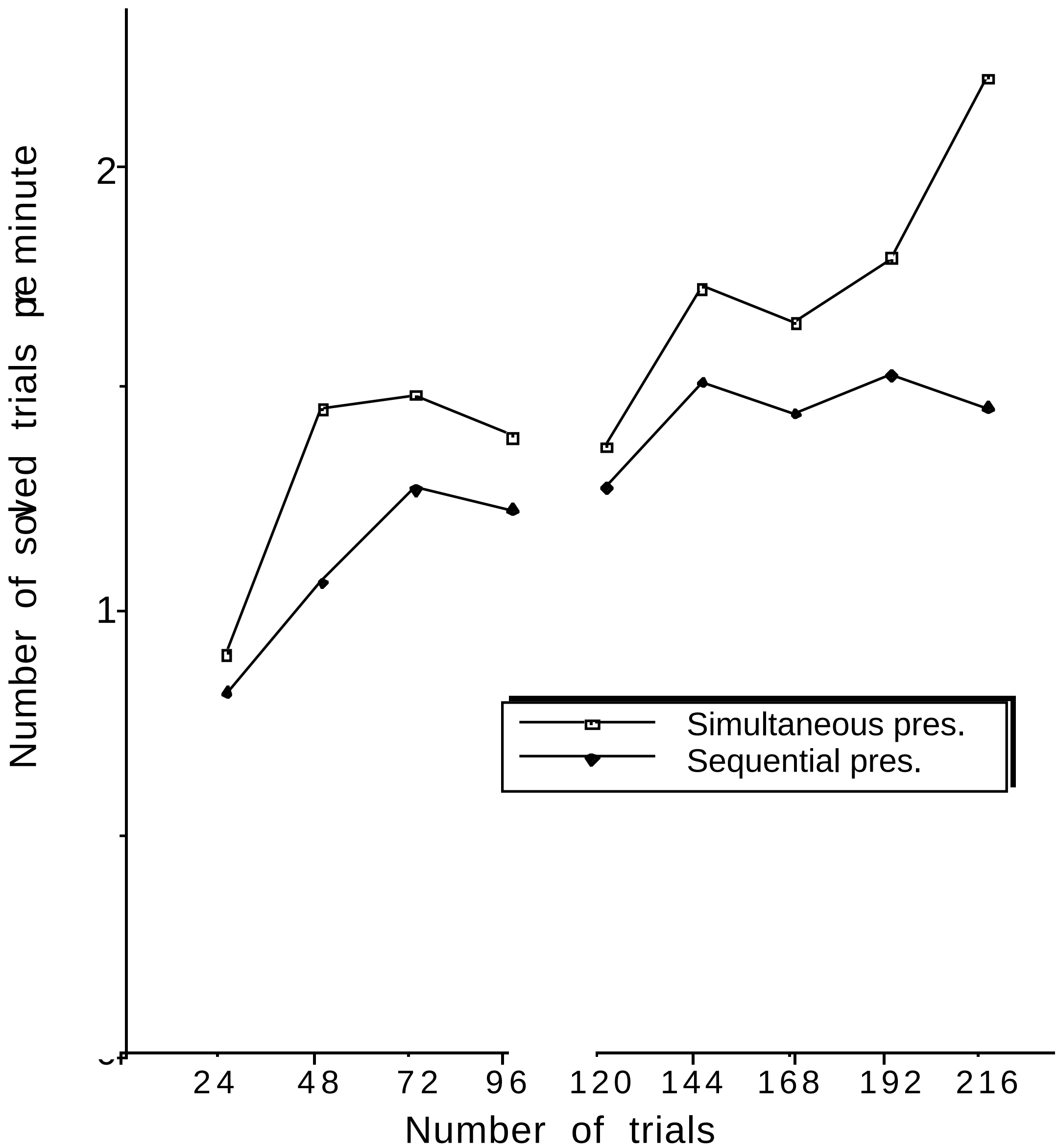
Number of solved trials per minute
2
1
0
24
48
72
96
120
144
168
192
216
Number of trials
Simultaneous pres.
Sequential pres.

Fig 3

# Experiment 3

This study tested three hypotheses:

a, The effect is real and can be found in a controlled laboratory setting.

b, The effect is due to an interference in working memory between data used to solve the problem and data used in the process of communicating with the system, an interference which is present in the sequential case but not in the simultaneous case.

c, The effect is due to the ability of humans to detect and utilize visual patterns in visually presented data.

These hypotheses are derived from items 1,4 and 5 in the list presented above.

## Method

### The task

A new task was constructed for two reasons. Firstly, the testing of the hypotheses concerning interference in working memory and the utilization of visual patterns required that another task was used. Secondly, the generality of the effect needed to be tested.

The chosen task should consequently be such that the information available through visually perceivable patterns could be manipulated, that the strain on working memory could be manipulated and that it should be of a very different type than the previously used task.

As a result a task modeled from a worksituation found in industry was selected. Its content is the selection of two subcontractors out of a group of four on the basis of either the price of their product only or a combination of the price (always in the range of 10 to 99 SEK per part), a quality measure of the product (expressed as a percentage between 10 and 99)) and the past reliability of the subcontractor (also expressed as a number between 10 and 99). The integration rule for the three factors was: total score = quality + reliability - price. Two additional rules were also in effect - (1) if all four possible subcontractors had values that differed ±5 units, a cartel could be suspected and none should be selected, (2) if all four possible subcontractors had quality and reliability values above 70 and a price below 30, then all four should be selected. Thus there were eight alternatives to choose from in each trial.

The values of each subcontractor were presented in a window with a white background. In that window either only the price (the low memory load condition) or the price, the quality measure and the reliability measure (the high memory load condition) were shown. In each window the values could be shown either by numerals (the numeric condition) or by bar graphs (the graphic condition). Finally, as in experiments 1 and 2, the subject could be shown one subcontractor-window at the time during each trial, determining the subcontractor to be shown by pressing "7", "8" "9" or "-" on the numerical keyboard, or all four subcontractor-windows simultaneously.

The same apparatus as in the previous experiments was used.

## Design

The resulting design is a 2x2x2 split-plot design with the within subject factor being sequential or simultaneous presentation, and the between subjects factor being numeric or graphical presentation and low or high memory load.

As in the previous experiments the subjects indicated to the system that they had reached a decision by depressing the space-bar on the keyboard (this was true for all conditions). The time elapsed from the start of the trial to this key-press was recorded and used as the primary measure. This means that the time used by the subjects to transmit their decision to the system was not included in this measure. Whenever the space-bar was depressed the subcontractor window(s) disappeared and a response screen was displayed. It consisted of a menu of the eight possible alternatives. The subjects indicated their choice by entering the number of the alternative they had chosen.

To eliminate the effects of a possible accuracy for speed trade-off the subjects were instructed to be certain to be right before they indicated to the system that they had reached a decision. Furthermore, if they still gave an incorrect answer, the system returned to the same trial and the previously recorded time was added when they again depressed the space bar. The errors on each trial, if any, were also recorded.

### Subjects

Twentyfour students, 17 male and 7 female, aged between 20 and 33 served as subjects, 6 in each experimental group. They were paid 100 SEK each for their participation.

### Procedure

Each subject was randomly assigned to a condition and then correspondingly received a description of the task and the rules needed to solve it. After being given five minutes to read the material the subject was taken to the computer system and shown how to run it. Through a series of 48 trials, 24 with a simultaneous presentation and 24 with a sequential presentation, the subject practiced the task and the running of the system. When these 48 trials were completed the experiment commenced which also consisted of 24+24 trials.

Half or the subjects in each condition were given the 24 sequential trials first in both the practice session and the experimental session and the other half were given the 24 simultaneous trials first in both the practice session and during the experiment.

## Results and discussion

As in experiments one and two the subjects followed the instructions and there were few errors made.

The distribution of the time data was very skewed violating the assumptions of parametric statistics such as ANOVA. Due to the design of the experiment, however, the three hypothesis can be tested by means of non-parametrical methods. Since the sequential-simultaneous presentation factor was varied within subjects a difference score for each subject was computed by subtracting the mean time of the 24 simultaneous trial of each person from the mean time of the same persons 24 sequential trials. All subsequent analyses were carried out on these difference scores.

To test the hypothesis that the effect is real the difference score was tested by means of the Wilcoxen test of signed differences. This showed that the two distributions differed significantly ($p < 0.001$). Since it is reasonable to assume that the two distributions have the same form this can be interpreted as a difference between the medians of the two distributions. The median being 1.72 seconds in favour of the simultaneous presentation.

To test the hypothesis that the effect is due to an interference in working memory between data used to solve the problem and data used in the process of communicating with the system, the difference scores for the low and the high memory load conditions were compared by means of the Mann-Whitney U test. This test showed that the two distributions differed significantly ($p<0.05$). With the same assumption as above this is interpreted as difference between the medians of the two conditions. The median of the difference scores in the low memory load condition was +1.43 seconds and in the high memory load condition +4.40 seconds.

To test the hypothesis that the effect is due to the ability of humans to detect and utilize visual patterns in visually presented data the difference scores for the numeric and graphical condition were compared, also by means of the Mann-Whitney U test. The test showed that there were no significant differences between the two conditions. The median of the difference score for the numeric condition was +1.44 seconds and for the graphical condition +2.03 seconds.

In view of these results the hypothesis that the effect is real cannot be rejected in this experiment. Together with the results of the previous experiments, using a very different task, this provides a solid piece of evidence.

The explanation of the effect seems to mainly lie in the interference in working memory between the decision making task and the task of controlling the computer interface.

The hypothesis concerning visual patterns can be rejected. It seems unlikely that it is the explanation of the effect.

It is worth noting that although the numerical/graphical presentation factor had no effect on the superiority of the simultaneous presentation over the sequential, there might exist an interaction between numerical/graphical presentation and memory load.

In the low memory load condition the median of the decision times is +5.13 seconds for the numerical displays and +6.35 seconds for the graphical displays. In the high memory condition the median for the numerical displays is +15.26 seconds while it is +9.95 seconds for the graphical displays. Given the nature of the data there is no meaningful way to statistically analyze this interaction and it is left to further studies to examine it.

# General discussion

If decision making and control of the human - computer interface should be regarded as two concurrent tasks competing for the resources of working memory, as these studies indicate, then this has implications extending beyond the issue studied. The main object when constructing interfaces intended for use in decision making situations, for instance, would be to see to it that the interface requires as little action as possible on behalf of the decision maker during the decision forming period. Not only should the need for paging or scrolling be avoided but also the need for calling up additional windows, replying to modal dialogue boxes, resizing or rearranging windows etc. This in turn implies that the designer of the interface has to, as a prerequisite to the design, identify all major decision making situations of the intended users, the volumes of data in which the needed data for those decision are to be found and pre-determine a specific layout for these data and the windows in which they are presented.

If user actions are needed, in spite of careful designing, during decision making situations these should be as little demanding as possible on the resources of working memory.

It is also worth noticing that if a pre-determined design is inappropriate in relation to the real need of the user, such a design can be an extremely poor one since a lot of action would then be required on behalf of the user to find the relevant data. The designing of an effective interface thus becomes an act of balancing the need for pre-determined layouts and the risk of "over-determining" parts of the interface.

These studies leave a number of questions unanswered, for instance the question of how big a simultaneous presentation of data can become and still be effective. What can be noted is that in terms of visual angle these studies employed a full screen extending app. 30 deg in the horizontal direction and app. 20 deg in the vertical direction.

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