# Visual Attention to Repeated Internet Images:

# Testing the Scanpath Theory on the World Wide Web

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RUNNING HEAD: Scanpath Theory on Web

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## Abstract

The somewhat controversial and often-discussed scanpath theory of visual perception was tested using Web pages as visual stimuli. In 1971, Noton and Stark defined "scanpaths" as repetitive sequences of fixations and saccades that occur upon re-exposure to a visual stimulus, facilitating recognition of that stimulus. Since Internet users are repeatedly exposed to certain visual displays of information, the Web is an ideal stimulus to test this theory. Eye-movement data were recorded for subjects' repeated viewings of three kinds of Internet pages -- a portal page, an advertising page and a news story page -- over the course of a week. Scanpaths were compared using a string-edit method to measure resemblance between sequences.



Keywords
Eye movement, eye tracking, Internet imagery, optimal matching analysis, scanpath, sequence comparison, string edit, World Wide Web

Since news sites emerged on the Web scene in 1994, followed by banner advertising in late 1994 and portal pages in 1996, Internet users have been repeatedly exposed to certain visual displays of information on their computer screens. Users of online newspapers read multiple news stories with screen after screen of text displayed in the same visual pattern. Heavy users of a product or service are likely to call up the corporate home page for updated product information or to make a purchase online multiple times before the image is changed. And Web users access the Internet through the same portal page time after time seldom, if ever, changing their starting-page default.

These common practices of Internet users make the Web a natural place to test a somewhat controversial and often-discussed theory of visual perception, that of the existence of "scanpaths." Noton and Stark (1971a, 1971b) defined "scanpaths" as repetitive sequences of fixations and saccades. Fixations are when the eye is relatively immobile and indicate the area where attention is being allocated (Rayner, 1995). Saccades are the quick jumps of the eye from area to area, during which vision is essentially suppressed (Yarbus, 1967).

Noton and Stark’s scanpath theory (Noton & Stark, 1971a) predicts that a subject scans a new stimulus during the first exposure and stores the sequence of fixations in memory as a spatial model, so that a scanpath is established. When the subject is re-exposed to the stimulus, the first few eye movements tend to follow the same scanpath established during the initial viewing of the stimulus, which facilitates stimulus recognition.

Research also indicates that when a subject is presented with a blank screen and told to visualize a previously seen figure, the scanpath is similar to when he or she viewed the figure (Stark, 1994). According to the scanpath theory, a spatial model, considered a precognitive, perceptual model, is assumed to control the sequences of eye movements. Noton and Stark asserted: "The internal representation of a pattern in memory is a network of features and attention shifts, with a habitually preferred path through the network, corresponding to the scanpath. During recognition, this network is matched with the pattern, directing the eye or internal attention from feature to feature of the pattern" (Noton & Stark, 1971a, p. 940).

Noton and Stark (1971a) argued that control of the eye by specific features in the visual is improbable because of the differences in scanpaths of different subjects for a given pattern. They also rejected the explanation that subjects are driven by habits because of variation in scanpaths of a given subject for different stimulus patterns.

Ellis and Smith (1985) elaborated on Noton and Stark's scanpath theory by suggesting that scanpaths can be generated by completely random, stratified random, or statistically dependent stochastic processes, but they did not test these conjectures. A completely random process assumes that each element of a visual has an equal probability of being focused on during each fixation. A stratified random process assumes that the probabilities of visual elements being fixated reflect the attentional attractiveness of those elements, but they do not depend on previous fixations. The statistically dependent stochastic process specifies that the position of a fixation depends on previous fixations. In view of the perceptual processes that are assumed to underlie eye movements, Rayner (1995) and Stark and Ellis (1981) believe it is unlikely that saccades from one fixation point to another are generated by either completely random or stratified random processes and look toward statistically dependent stochastic processes as explanation.

Early studies on eye movements while subjects viewed scenes and pictures also have provided evidence that visual exploration or search is not random. Eye movements are related to the content of the scene (Brandt, 1940; Buswell, 1935; Llewellyn-Thomas, 1968; Yarbus, 1967). The pattern of fixations and saccades could be changed by altering the pictures or the task. Content that contains unique detail also dramatically influences the pattern of fixations and saccades, as such detail draws more attention than common or expected visual information. Viewers fixate on unique regions of visual scenes sooner and more frequently and for longer durations than any other area of the visual scene (Antes, 1974; Mackworth & Morandi, 1967).

Some studies focus on the role that peripheral vision plays in determining where a subject will look next. Parker (1978) speculated that peripheral vision might be the major force driving the scanpath. However, eye-movement studies on ambiguous and fragmented figures showed that the same physical stimulus results in different scanpaths depending upon the changing perceptual representation of the viewer (Ellis & Stark, 1978; Stark & Ellis, 1981). Therefore, peripheral vision may not play a major role in generating the scanpath. Brandt and Stark (1997) pointed out that since there was no actual diagram or picture in their visual imagery study that “[i]nput from foveal or peripheral vision cannot play a role in generating scanpath eye movements during imagery" (p. 32).

## Testing the Scanpath Theory

In recent years researchers have used Markov models and string-edit methods to test the scanpath theory. For example, Pieters, Rosbergen and Wedel (1999) used Markov models to compare scanpaths in a study of repeated exposures to print advertisements. Stark and Ellis (1981) used Markov analysis to quantify the similarity of eye movements. Brandt and Stark (1997) used string-edit analysis to compare the viewing pattern of a diagram of an irregularly checkered grid displayed on a computer screen with the eye movements while subjects imagined that particular grid. Using string-edit analysis, Zangemeister et al. (1995) and Gbadamosi et al. (1997) found evidence for scanpath sequences in their subjects' eye movements while similarly performing real viewing and visual imagery.

A Markov process is a stochastic model for the probabilities that the viewers' eyes will move from one visual element to another. The assumption is that scanpaths across visual elements can be described by a first-order Markov process—that is, each eye fixation only depends on the previous one. Three possible stochastic possibilities underlie visual scanning: this first-order dependence, plus reversibility and stationarity. Reversibility means that saccades from element A to B occur as often as saccades from B to A (Ellis & Smith, 1985), and stationarity predicts the scanpaths of viewers exposed repeatedly to the same visual remain constant across exposures.

Pieters, Rosbergen and Wedel (1999) concluded that scanpaths remain constant across repeated exposure to advertising stimuli and across experimentally induced and naturally occurring conditions. They also concluded that scanpaths obey a stationary, reversible, first-order Markov process.

Using a different means of comparing scanpaths -- the string-edit method -- Brandt and Stark (1997) also found evidence supporting scanpath theory. Specifically, they found that eye movements during imagery are not random but reflect the content of the visualized scene. They concluded, therefore, that an "internalized, cognitive perceptual model must be in control of these scanpaths" (p. 32).

Abbott and Hrycak (1990) noted several advantages of string-edit methods for studying event sequences and outline several difficulties with Markovian sequence models. First and foremost, they argued, the sequence-generating process may have a longer history than the immediate past typically used in Markov analysis. Second, Markov models describe the stochastic processes that generate observed sequences, and can be used to explore the goodness of fit of a predicted model, but don't address the questions of whether there is a typical event sequence for a given process. Abbott and Hrycak (1990) argued that the direct testing of the Markov model -- in terms of actual resemblance between generated and observed sequences -- requires a technique for assessing similarity between sequences, categorizing sequences, and identifying typical sequences. String-edit analysis affords all of these techniques.

In this study, we test Noton and Stark's scanpath theory on different kinds of images widely used on the World Wide Web -- a news page, an advertising page and a portal page. We compare recorded scanpaths using a string-edit method, a technique that measures resemblance between sequences by means of a simple metric based on the insertions, deletions and substitutions required to transform one sequence into another. While several researchers such as Brandt and Stark (1997) and Salvucci and Anderson (2001) have used string-edit methods to study eye-path sequences, relatively few studies using this method have been reported despite the homology between eye-tracking data and string-edit methodology. To our knowledge, this is the first study in which repeated exposures to Web page visual stimuli have been examined using eye tracking for measurement and string-edit methods for analysis.

## Method

### Participants

The participants for the study were eight students at a large western university (four males and four females). Their average age was 22.5 years. They were compensated for participating in the three-session study. All subjects were regular users of the Internet, reporting an average of almost nine hours a week of usage.

### Apparatus

The eye-movement data was collected by equipment developed by ISCAN Inc., a well-established Burlington, Mass., company that has been making eye-tracking equipment for 20 years. Specifically, the equipment used was the RK-426PC Pupil/Corneal Reflection Tracking System, which uses a corneal reflection system to measure the precise location of a person's eye fixations when looking at a visual display on a computer monitor.

### Fixation Criterion

Even though the processor of the RK-426PC system operates at a sample rate of 60 Hz a second and the default setting for a fixation is 40 milliseconds with an area of 5 pixels by 3 pixels, the setting was changed to conform to research findings of the last 50 years regarding what constitutes a fixation. The setting was changed to 100 milliseconds with an area of 10 pixels by 6 pixels. Eye-movement researchers such as Yarbus (1967) believe an average fixation lasts between 200 and 500 milliseconds. Furthermore, eye-movement researchers studying media images such as those in print (Fischer et al., 1989) and on television (Baron, 1980) have established 100 milliseconds as the minimum amount of time necessary for a pause to be considered a fixation. Researchers studying reading concur (Stark, 1994). They argue fixations of 100 milliseconds or 0.10 seconds are representative of reading behavior.

Data Gathering

Each of the eight participants reported to the eye-tracking lab three different days separated by 48 hours -- on a Tuesday, Friday and Monday. Each day participants viewed three different Web pages while their eye movements were recorded.

At the lab, a participant was seated in front of the computer monitor and was told that he or she would be looking at three Web pages for a brief period of time. Participants were told not to click on any links. After completing a task to calibrate the scanning equipment, the participant was shown a Web page. The order of exposure to the three pages was varied each session.

Eye-movement data for a 15-second exposure to each page was recorded. Previous research (Loftus, 1976) has established that eye fixations on essential information in a visual display occur within the first few seconds. Brandt and Stark (1997) deemed 10 seconds to be sufficient exposure in their study of repetitive sequences of visual fixations. An additional five seconds was allowed in this study because of the increased visual complexity of Web pages as opposed to the irregularly checked diagrams used by Brandt and Stark. After pretests, 15 seconds was deemed to be sufficient for participants to completely examine the Web pages. The calibration was checked between display of the second and third Web pages used in this study.

Stimuli

The three Web pages used as stimuli in this study were chosen for a number of reasons. Each page represents a distinct category of visual imagery on the Web. The portal page, used as a starting point for content on the Web, consists of a large number of hyperlinks and dialogue boxes for search functions and email. The advertising page is highly visual and extremely colorful and is used to "build the brand" and sell the product. The news page displays mostly typography of various sizes for headlines, bylines and body copy and is designed to convey the latest information in an efficient manner.

The portal page and the online advertisement used in this study are completely contained in the first view, not forcing the viewer to scroll, thus simplifying the data analysis. While scrolling was required to read the entire news story, participants who scrolled would remain in the text region.

Finally, the string-edit analysis requires defining a sequence alphabet, in this case a set of target regions in each stimulus. Web pages that allowed simple grids to be superimposed over their images were necessary for use in this study (see Figures 1a, 1b, 1c). The Web pages selected were deemed to be relatively simple in layout yet contain enough complexity so that the sequential processing of the subfeatures could occur, thus producing the necessary sequential eye movements that define a scanpath. Brandt and Stark (1997) emphasized that the stimulus materials used in this sort of analysis required "a set of subfeatures whose positional encoding required careful review of the spatial layout by the subjects" (p. 34).

## Procedure

### Definition of Visual Areas

Even though the apparatus allowed for the location of each fixation to be precisely determined to an accuracy typically better than 0.3 degrees over a +/-20 degree horizontal and vertical range, our application of the string-edit method requires assigning fixations to target areas. This requirement works well for the stimuli used in this study. In news and advertising circles, for example, the goal is to understand what elements were looked at and how frequently they were looked at, instead of the exact coordinates of each fixation.

In addition, defining areas of fixation avoids the complex question of exactly how much of the visual field is covered in each fixation. This occurs because of foveal (yellow spot) and parafoveal (the surrounding area of the retina) vision. Mackworth (1976) used the term "useful field of view" (p. 307) to define the area around the fovea from which information is effectively processed. Gould (1976) used a zoom lens analogy to describe how observers can selectively attend to different-sized areas of a visual display.

### Sequence Comparison

The first step in comparing the eye-path sequences in this study was to define a sequence alphabet for each Web site. This was accomplished by assigning each defined target area on each Web page an alphabetic code. The second step was to define the eye-path sequence for each subject's viewing of each Web page by recording the sequence of fixations by the defined target area within which the fixation occurred (called "target tracing" by Salvucci and Anderson [2001]). For example, a viewing beginning with a single fixation in area "A" followed by three fixations in area "C" would generate a sequence beginning "ACCC...". As sequences in this case cannot be compared across stimuli, we perform separate comparisons within each of the three sets of 24 sequences (three sequences for each of eight subjects).

Next, optimal matching analysis (OMA) was used in this study to compare these coded sequences. OMA is a generic string-edit tool for sequence comparison (Holmes, 1997) when each sequence is represented by well-defined elements drawn from a relatively small sequence alphabet, in this case visual areas. OMA produces a numerical index -- the Levenshtein distance -- of the dissimilarity between any two sequences, computed as the smallest possible cost of elementary operations of insertion, substitution and deletion of units required to align or transform one sequence into another (Sankoff & Kruskal, 1983; Abbott & Forrest, 1986) (see Figure 2 and Figure 3). Similar sequences will, when compared, have smaller dissimilarity indexes; the more different two sequences, the greater the index. In this application of the method, the dissimilarity index ranges from 0 for identical sequences to 1 for maximally dissimilar sequences.

It should be noted that alignments may use a combination of substitutions and indels (insertions and deletions) to produce the Levenshtein distance. In their application of the string-edit method, Brandt and Stark (1997) set equal substitution costs for all pairs of sequence elements. We apply a more refined approach to substitution costs. In this particular study, substitution costs could have been set in at least three ways: (1) at a value equal for all substitutions, following Brandt and Stark (1997); (2) by distinctions between content forms of the regions, such that costs between regions in related categories would be lower (e.g., site navigation vs. content navigation) whereas costs between categories would be higher (e.g., navigation types vs. content types); or (3) by some measure of distance such that regions "closer" to each other can be substituted at less cost than regions further apart. This last approach was used in this study as we believed the first approach lacked requisite variety and the second approach was unsuitable for testing a theory of physical scanpaths.

In this study, the substitution values were based on the inverse of the physical adjacency of target areas—that is, the number of alternative target regions in a direct path between the two points. For example, a pair of contiguous target areas, on a page for which the longest direct path between the centers of two target areas traversed five regions, would be assigned a substitution cost of 0.20.

The contribution to the Levenshtein distance by the length of the compared eye-path sequences (defined by the number of fixations in each) is an issue that has to be considered in OMA. To adjust for the role of sequence length in shaping the total cost of alignment, the inter-sequence distance is determined by dividing the raw sum alignment cost by the length of the longer sequence in the sequence pair. This makes the distance relative to length and comparable across pairs of varying lengths.

Next, WinPhaser software (Holmes, 1996) was used to generate a sequence distance matrix of distance indexes for each possible pair of sequences for each stimulus. WinPhaser's OMA package uses a dynamic programming algorithm by Andrew Abbott. UCINET software (Borgatti, Everett & Freeman, 1992) was used to perform non-metric multidimensional scaling and hierarchical cluster analysis on the distance matrices. Scaling arranges the sequences in n-dimensional space such that the spatial arrangement approximates the distances between sequences; cluster analysis helps to define "neighborhoods" of similar cases within that n-dimensional space.

## Results

Plots of the multidimensional scaling solution in two dimensions are displayed for the portal stimulus (Figure 4a) , advertising page stimulus (Figure 4b), and news page stimulus (Figure 4c). The two-dimensional solution to multidimensional scaling was used for convenient display because we are more interested in recognizing neighborhoods than in defining dimensions. The figures also indicate the most central eye path sequence (that is, the sequence or sequences with the least mean distance from other sequences). In addition, in each set the most similar sequence pairs are noted, as well as the two most dissimilar sequence pairs.

It is worthwhile to examine several of these cases, as they underscore the operation of the string-edit method used here and aid interpretation of the results. Figure 5 displays eye path sequences for four viewings of the portal stimulus. According to our string-edit results, the paths for subject 4 and subject 5 are the most dissimilar in the set. Visual inspection suggests this may stem from the different attention, evident in the paths, to upper and lower areas of the display. Conversely, the lower two paths in Figure 5 are more similar; they are from the same person (subject 8) and represent "central" sequences in the set. They are characterized by more apparent similarity than the previously noted paths, and show attention distributed across the width of the middle tier of regions.

Visual examination of the spatial arrangement of the sequences in Figure 4 reveals support for scanpath stability. In the case of the portal stimulus, for subjects 1, 3, 4, 6 and 7 we find the eye paths from the three separate viewings to be co-located in relatively small areas. In addition, two of the three eye path sequences are neighbors for subject 2. The advertising page stimulus reveals somewhat less stability of paths, as only subjects 2, 6 and 8 appear to form small neighborhoods for all three sequences. The news page, which invites top-down, left-right processing of its contents, displays tighter co-location of most cases. This is especially notable for subjects 2, 6, 7 and 8; however, subjects 1, 4, and 5 each provide a pair of closely located sequences as well.

Cluster analysis results provide another approach to discerning neighborhoods of similar sequences and are superimposed on the multiple-dimensional scaling results in Figure 6. The clustering results suggest the three-dimensional solution may have been superior, as the “worm-shaped” clusters in some of the diagrams may reflect the greater stress of forcing the items into the less-optimal fit of two-dimensional space. The clustering reveals families of sequences across subjects; note, for example, the cluster composed of a pair of eye path sequences from subject 1 and a pair from subject 6 in Figure 6a (portal stimulus). Similar features are found in the other plots. Figure 6b (advertising stimulus) reveals a larger cluster to be composed of sequences from four subjects (subjects 2, 4, 5, and 8), while in Figure 6c (news page stimulus) one of the clusters is composed of single sequences from four different subjects. Such cross-subject scanpath similarity may bear witness to the interplay of design features and individual scanpath preferences.

In our data, the eye path sequences for the textual stimulus (Figure 4c and Figure 6c) are more similar to each other than are the most-similar sequences for the portal or advertising stimuli, perhaps because the text region tended to keep the fixations once it had captured them. Given this “pull,” remaining within-subject differences in the scanpath for the textual stimulus are interesting as they may suggest either (1) lack of stability over time of the person’s scanpath, or (2) a confounding memory effect wherein familiar textual material is scanned differently from new material (e.g., attention decrement).

In a similar fashion, the strong within-subject resemblances between sequences for the portal and advertising stimuli, which in design are less governed by left-right/top-down conventions, are notable, as they suggest either: (1) scanpath stability or (2) particular page features tending to capture attention in the same general sequence. Note, however, that when different subjects show high within-subject scanpath resemblance, but nevertheless with marked difference between subjects, we can conclude personal scanpath preferences do indeed have some explanatory power.

## Conclusion

Our results are mixed. Some individuals show scanpaths that resemble each other over time. However, we also found many instances in which the most similar sequences were from different subjects rather than from the same subject, suggesting strong stimulus influences. On the other hand, the clusters tend to include pairs of sequences from the same subject. The fact that clusters of sequences typically contain paths from multiple subjects suggests that other forces may be important, such as features of the

Web page or memory. These could be tested in future research with carefully manipulated page versions.

This study is descriptive in nature with no tests of significance. To have significance tests, we would need to determine a critical value for how much Levenshtein distance is needed before we consider two sequences to be significantly different. A crude significance test could be generated from Monte Carlo simulations in future research.

By visual examination of our data, we suspect that paths tend to drift over time for a given subject. These questions present themselves: Is there an increased tendency with the passing of time to ignore material on the top of Web pages? Do the paths become simpler? Do viewers dwell longer on selected regions of particular interest? Does task fatigue result in shifts in visual attention?

In summary, on the World Wide Web, with somewhat complex digital images, some viewers' eye movements appear to follow a "habitually preferred path" across the visual stimulus as asserted in the scanpath theory of Noton and Stark (1971a). Given the still-considerable variation in paths between and across subjects, much more research is needed to explore the influence of scanpaths, content and form on sequences of eye movement.

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Figure Captions

Figure 1. Target region grids for portal, advertising and news web page stimuli.

Figure 2. Sequence alignment or matching through insertions, deletions and substitutions.

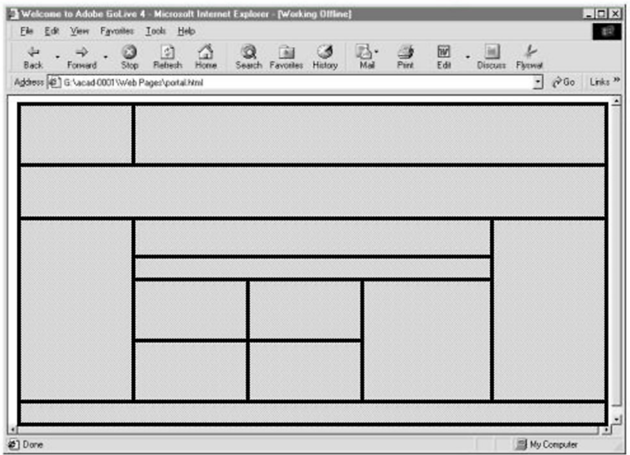
Figure 3. Levenshtein distance: the lowest cost alignment.

Figure 4. Multidimensional scaling solutions in two dimensions for the portal, advertising page, and news page stimuli.

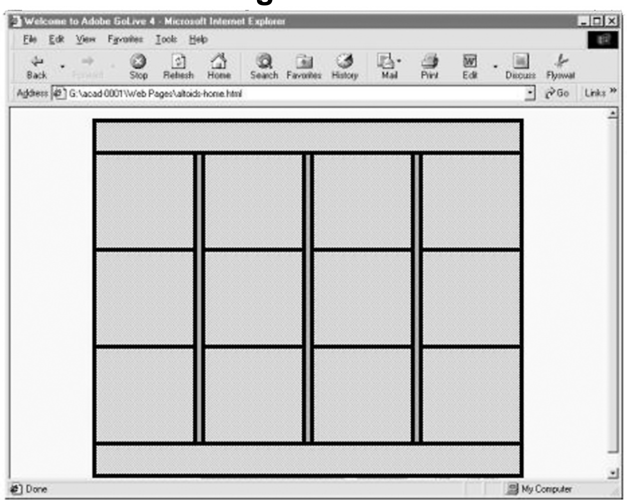
Figure 5. Example eye path sequences for the portal stimulus.

Figure 6. Multidimensional scaling solutions in two dimensions for the portal, advertising page, and news page stimuli with cluster analysis results superimposed.

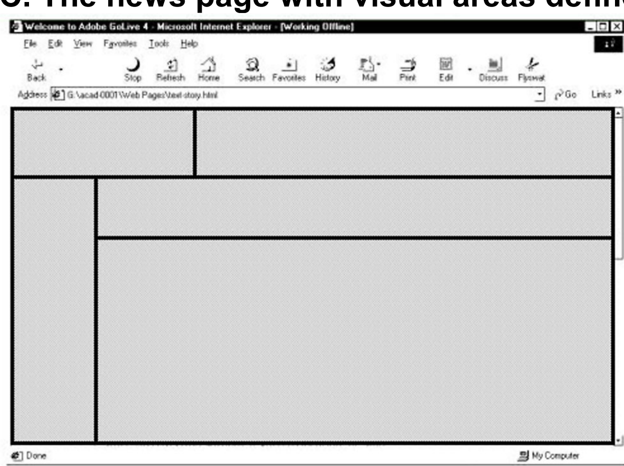
A. The portal page with visual areas defined.




B. The advertising site with visual areas defined.




C. The news page with visual areas defined.



Sequence 1: **A B A A A A A B A A**
Sequence 2: **A B C A B C A B C A**
Sequence 3: **C B C C C C C B C C**

```
A B A A A A A B A A
    |   | |     |
A B C A B C A B C A
```

Four substitutions to align seq. 1 & seq. 2.
Distance = .4 (4/10)

```
A B C A B C A B C A
|     | |   |     |
C B C C C C C B C C
```

Five substitutions to align seq. 2 & seq. 3
Distance = .5

```
A B A A A A A B A A
|   | | | | |   | |
C B C C C C C B C C
```

Eight substitutions to align seq. 1 & seq. 3
Distance = .8

Sequence 1: **A B A C A C B B A C**

Sequence 2: **A B A A C A C B B A**

```
A B A C A C B B A C
      | | | |   | |
A B A A C A C B B A
```

Six substitutions to align

Distance = **.6**

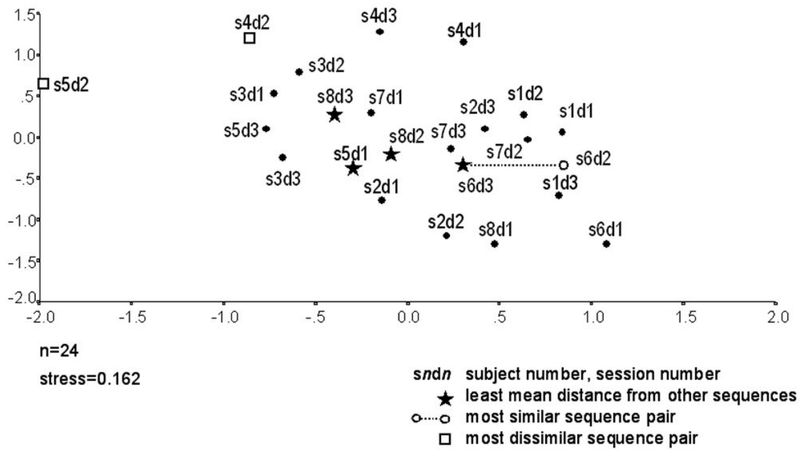
```
A B A   C A C B B A C

A B A A C A C B B A C
      ↑               ↑
   delete          insert
```

Two indels to align

Distance = **.2**

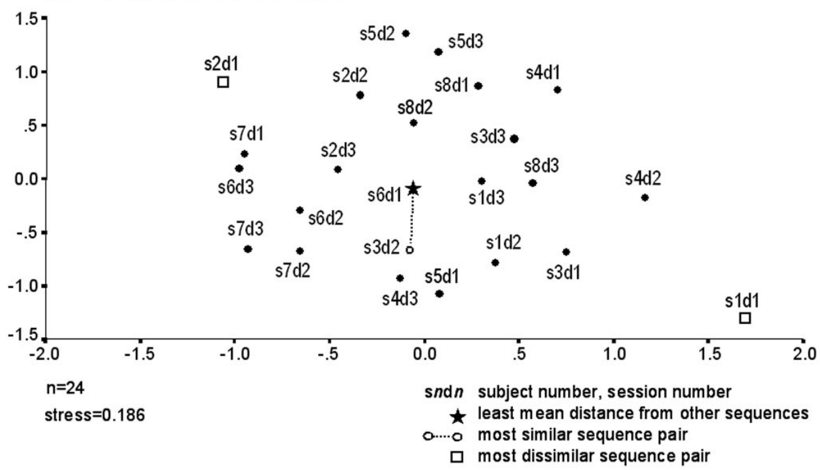
## A. Eye path sequences for the portal page stimulus

MDS solution in 2 dimensions



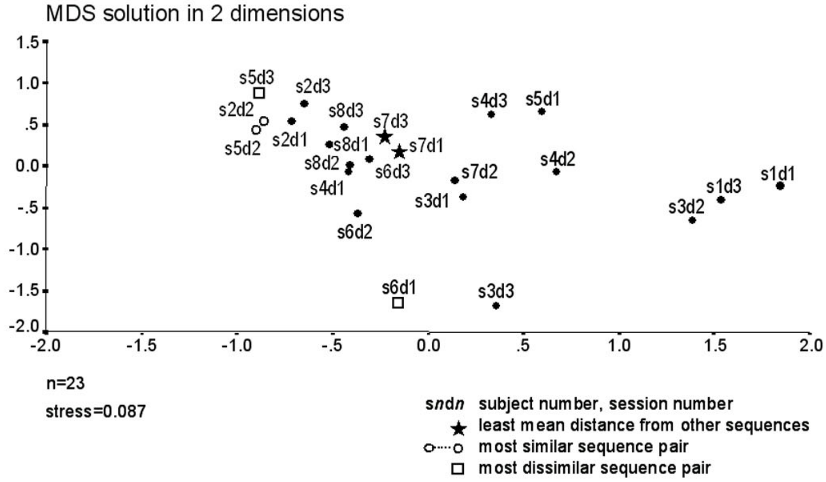

## B. Eye path sequences for the advertising page stimulus

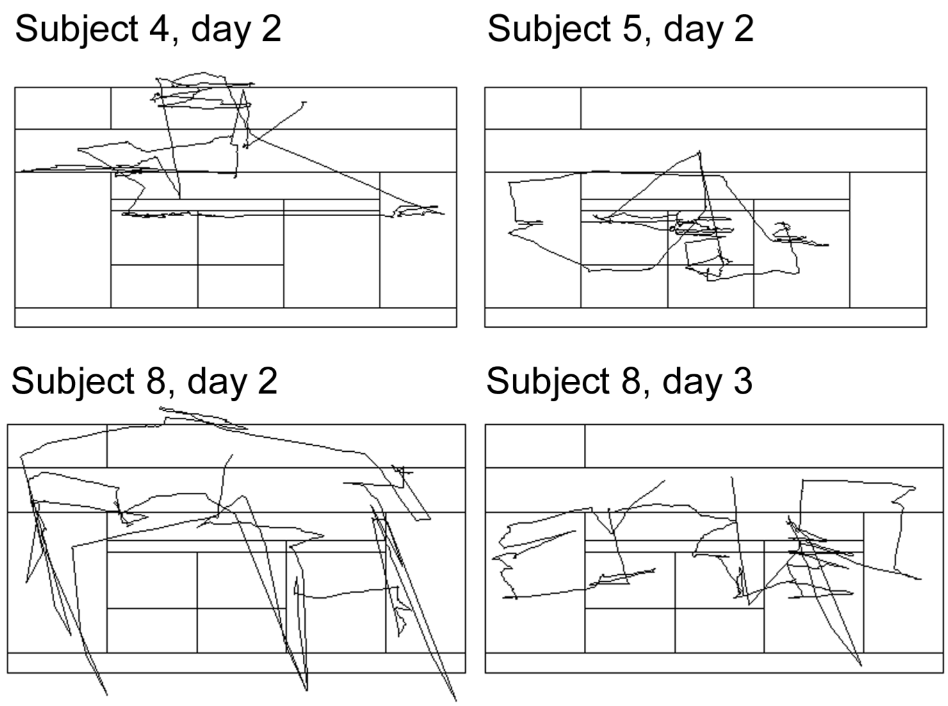
MDS solution in 2 dimensions




## c. Eye path sequences for the news page stimulus

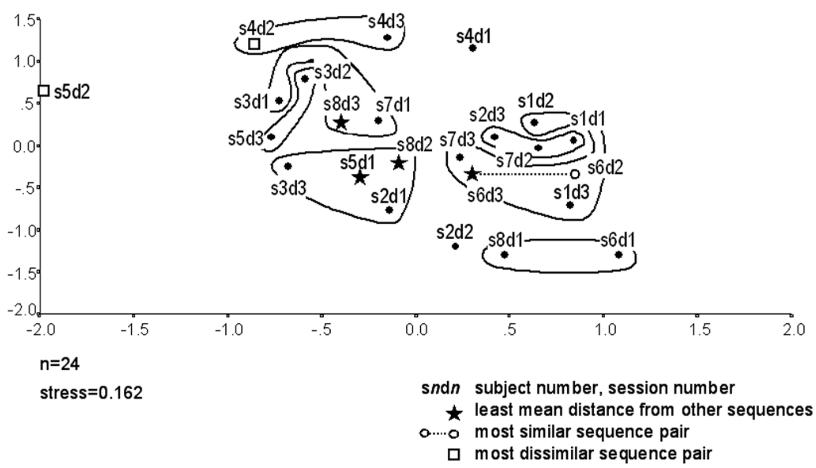
MDS solution in 2 dimensions




Subject 4, day 2
Subject 5, day 2
Subject 8, day 2
Subject 8, day 3

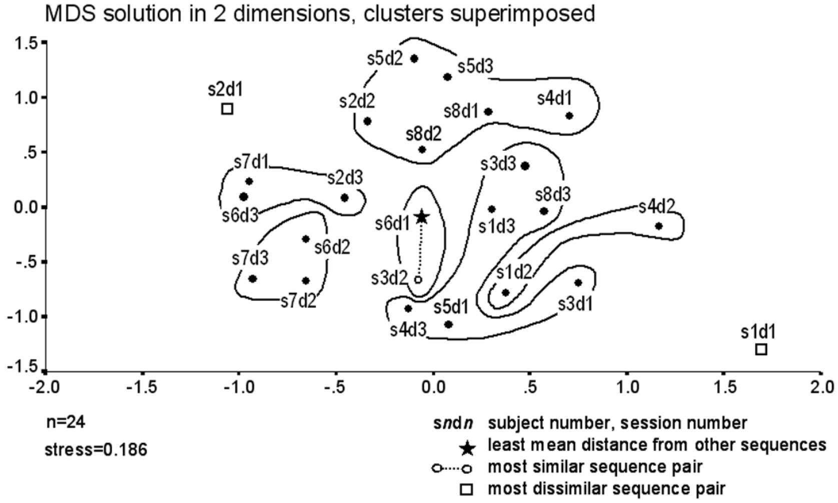
## A. Eye path sequences for the portal page stimulus

MDS solution in 2 dimensions, clusters superimposed




## B. Eye path sequences for the advertising page stimulus

MDS solution in 2 dimensions, clusters superimposed




## C. Eye path sequences for the news page stimulus

MDS solution in 2 dimensions, clusters superimposed