Moticons: Detection, Distraction and Task

Lyn Bartram
Colligo Networks, Inc.
lbartram@colligo.com

Colin Ware
Data Visualization Lab
University of New Hampshire
colinw@cisunix.unh.edu

Tom Calvert
Technical University of British Columbia
calvert@techbc.ca

Abstract

In this paper we describe an empirical investigation of the utility of several perceptual properties of motion in information-dense displays applied to *notification*. Notification relates to awareness and concerns how dynamic information is communicated from the system to the user. The results show that icons with simple motions, termed *moticons*, are effective coding techniques and in fact outperform colour and shape codes, especially in the periphery. Comparisons of different motion types reveal how different attributes of motion contribute to attention, identification and distraction and provide initial guidelines on how motion codes can be designed to support awareness in information-rich interfaces.

Introduction

Users typically function in multi-task environments in which information is distributed across windows and applications and is not necessarily exclusive to the task at hand. For example, a financial analyst may be monitoring stock market quotes while reviewing a client's portfolio and evaluating performance patterns over time. Simultaneously she may be cued as messages to do with office administration arrive from her colleagues. Alternately, a telecommunications manager may be planning scenarios for equalizing phone traffic across variably-loaded channels while sporadic alarms indicate overloads on current routes. In both cases these users are being made aware of dynamic information outside the specific scope of the data they are using for their current tasks. In some cases certain types of dynamic information are contained in a dedicated display which the user must constantly monitor, such as a stock ticker or message flag. These displays are typically located on the periphery of a screen (McCrickard 2000, Maglio and Campbell 2000, Czerwinski et al. 2000). In other cases the changing information can be located anywhere in the visual field, such as mode information or element state directly tied to data objects in the displays (Sarter and Woods 1995, Mitchell and Sundstrom 1997).

Monitoring dynamic information can be a cognitively strenuous task which requires the user to examine the currently displayed information and decide whether it has changed, so it is preferable to explicitly alert the user to a change by a *signal*. Signals are graphical events which indicate to the user that something has happened in some area in the display. Replacing an "empty mailbox" icon with a "full mailbox" to show email status or animating the transformation of old text into new in a peripheral display (McCrickard 2000) are examples of signals. Signals are incorporated into peripheral awareness tools (McCrickard 2000, Maglio and Campbell 2000), messaging (Parsowith et al. 1998, Cutrell et al. 2000), state changes, system events, or alarms (Adams et al. 1995). They can also be used as navigation markers or guides to dynamically emphasise relevant points in a display.

Current information visualization interfaces rely heavily on graphical coding devices (also termed *display dimensions*) such as shape, colour, size, texture, orientation and position (Ware 2000). These schemes can be very effective in enabling information analysis because they are *mentally economical* (Woods 1991, Healey et al. 1995): rapidly and efficiently processed by the preattentive visual system rather than attentive effort. However, only a small amount of information can be encoded in each visual dimension. For example, a typical recommendation is that no more than eight colours be used to define information categories (Gilmore et al. 1989, Shneiderman 1986). For this reason there is a shortage of perceptually efficient codes than can be used in information-rich user interfaces.

One promising way of visually coding information is to use simple motion. Motion has a unique ability to attract attention over a large visual field and offers a rich graphical vocabulary. Its use has only recently become feasible due to the advent of fast graphics processors and supporting software technologies. However, compared with the use of colour coding, which is supported by a large literature of design guidelines based on decades of experimental studies, there has been little research relating to the effective design of motion codes. Such work is urgently needed because available technologies such as Javascript and image animation have led to a riot of moving and jiggling icons that compete for our attention. The notification studies described in this paper investigated the effects of moving icons, which we call *moticons,* as alerting mechanisms in situations where the user is engaged in a primary task and needs to be made aware when an event occurs outside the task area.

Background

Research into human perception tells us a great deal that is relevant to the use of icon motion as a coding mechanism. Of special interest is the fact that motion triggers a kind of orienting response, attracting a user’s attention, even when it appears in the periphery of the visual field (Faraday and Sutcliffe 1997).

Motion compares very favourably to colour and shape if we are concerned with designing icons to attract a user’s attention at the edge of a computer screen. The human visual system is very non-uniform with respect to our ability to resolve detailed information. For example, we can only resolve about one tenth of the detail about ten degrees of visual angle to the side of the point of fixation (Smith and Atchison 1997). Thus icons that rely on detailed shape to convey their meaning are only effective if directly fixated. Our ability to discriminate colour information is also very non-uniform across the visual field. In fact in the periphery we are almost colour-blind (Wyszecki and Stiles 1982). One of the great potential advantages of motion as an attention-getting device is that our ability to perceive motion falls off much less towards the periphery of the visual field. Peterson and Dugas (Peterson and Dugas 1972) confirmed this in an applied setting that showed static targets to be virtually invisible in the far field whereas moving targets were easily detected.

Our ability to see things at the edge of a computer screen may vary with our level of attention to the task we are performing. A “searchlight metaphor” has been used to model how attention falls off in the visual periphery as a function of the cognitive load or the stress level of an operator (Wickens 1992). A phenomena known as tunnel vision occurs under conditions of very high stress, but even under relatively low stress conditions the focus of attention narrows considerably (Williams 1985). Focusing attention in a visually “noisy” field requires the user to both maintain control of where she is attending and awareness of potentially interesting areas as conditions change. Woods defines several criteria for signals he terms *cognitive tools* to support control and direction of attention (Woods 1995): *accessibility* (i.e., the user should be capable of picking them up without losing track of current activities); *partial information* (the signal should carry enough partial information for the user to pick up whether to shift attention to the signalled area); and *mental economy* (the representation should be processed without cognitive effort).

Because other information can remain on the screen while a user attends to a moving signal, it may provide the required accessibility. Because motion can be registered in the periphery it may be ideal for conveying partial information, and because motion is pre-attentive it may have the required characteristic of mental economy. However, all of these qualities require experimental verification in task-related studies.

The human visual system is very good not only at perceiving but also at tracking and predicting movement. We can track up to five moving objects in parallel (Pylyshyn et al. 1993) without effortful context-switching. Hillstrom and Yantis (Hillstrom and Yantis 1994) suggest that it may not be motion *per se* that attracts attention, but rather the appearance of a new object in the visual field. These findings suggest that introducing extensive motion into user interfaces may be problematic. When a new object gains the attention of the tracking system, another object will typically be lost. This can lead to problems occurring with distracting irrelevant items. In particular the moving banner animations that grace many web pages may be particularly effective in distracting us.

Previous studies with moving icons

Blinking can be considered to be an elementary form of motion and much use has been made of blinking in user interfaces to attract and direct visual attention. In many systems it is the primary visual cue for alarm conditions. However, anecdotal evidence indicates that people find blinking excessively annoying and visually ineffective when too many items are flashing (who has not cursed the WWW HTML blink function?) In large-scale systems where alarms tend to propagate rapidly, over-flashing not only reduces effective alarm information but also renders the displays visually disturbing, distracting users from effectively perceiving the needed information from other representations (Gilmore et al. 1989,Sarter and Woods 1995,Woods 1995). Ware investigated the use of a simple moving icon as a “human interrupt” signal in the interests of seeing if this would evoke the same direct pull of attention as blinking or flashing without causing the associated irritation (Ware et al. 1992). Subjects performed a primary task and were told to respond by hitting a key when they noticed movement of one of two small icons on either side of the top of the display. The icon was a small bar which grew and shrank vertically in an smooth, oscillatory fashion. Amplitude, side and velocity of the movement were varied. There was no effect for amplitude or side, but increases in velocity led to an increase in the number of quick responses and a decrease in the number of long ones. The good average response times indicated that subjects had no trouble noticing the interruption without any reported irritation factor. Even the slowest times were acceptable and were reported to be less irritating.

One way of using simple animation is in illustrating a simple procedure. Baecker and Small animated icons to identify and explain their function (Baecker and Small 1990). The advantages of animation were particularly noticeable when the small size of icons meant a low resolution of information (i.e., intricate depiction was impossible). Ambiguity was reduced and users remembered the function of the particular icon better.

McCrickard and Stasko investigated how animated information could be used to maintain peripheral awareness (McCrickard et al. 2000). While subjects browsed through on-line text, additional information would appear in a secondary window in one of three ways: the words would fade slowly in, would scroll across the window, or would suddenly appear ("blast in"). None of these cues was found sufficiently distracting to impede the primary task, but as might be expected from the theory of perceptual onset (Hillstrom and Yantis 1994) the blast was the most effective in getting attention.

Motivation

The experiments in the detection and distraction studies reported here were designed to address a number of questions that relate to the use of motion signals as a cognitive tool (Woods 1995) for managing attention. A dual task design was used to simulate situations common in current desktop environments where the user is engaged on a primary task that takes most of her attention. We are interested in the kind of situation awareness where a change in an icon is used to signal some event, such as the arrival of mail, new users in a conference, or system events like a printer jam. Experiments 1 and 2 dealt with detection; Experiment 3 looked at distraction effects.

The first two experiments investigated how moving icons compare to both colour and shape in attracting a user's attention. A large screen display was used to address the issue of how far in the periphery motion can be effective compared to colour and shape. Large displays are becoming increasingly common as the focus for work-group activities; we believe that most of the results also apply to desktop displays, especially in multiple-monitor configurations. Such peripheral issues arise in interfaces any time users need to see dynamic information outside the foveal area. This happens frequently in several circumstances: multiple monitor configurations, large screens, or small peripheral awareness displays (see (McCrickard 2000) for a review). Indeed, even standard desktop 21" displays where information is located in tool- and menubars along the edges of the screen can result in poor information detection and discrimination due to peripheral effects (Maglio and Campbell 2000). Finally, in any environment in which users are not guaranteed to be looking straight ahead at a display all the time peripheral vision is a factor.

Experiments 1 and 2: Signal Detection and Identification

There were two experiments in the detection study. Experiments 1A and 1B compared how well simple motion cues were detected compared to colour and shape cues respectively and how these varied with distance from the locus of attention (the primary task window). Both detection rates and detection times were measured. Experiment 2 took a more ecological approach: it combined colour, shape and motion cues and investigated how well they performed in a more complex screen in both detection and identification: i.e., how accurately the subject could identify which object in the visual field had changed.

The first experiment had the purpose of evaluating the effectiveness of different kinds of motion, relative to colour change, or shape change, in signalling users across a wide visual field populated with icons. A wide field of view was used to investigate both near-field and far-field conditions. The cues were colour change, shape change and two linear motions (up and down) of the same frequency but different amplitudes. The first part (Experiment 1A) compared colour cues to motion cues. The second part (Experiment 1B) compared shape cues to the same motion cues. We measured the error rate and response time for detection (noticing that something had changed). Subjects performed both 1A and 1B in a single session; ordering was counter-balanced. We had five hypotheses for this experiment:

H1: Colour icon detection rates fall off as distance increases from the centre of attention and times increase (Experiment 1A).

H2: Moving icon detection rates are higher than colour detection rates and detection times are shorter (Experiment 1A).

H3: Shape icon detection rates fall off as distance increases from the centre of attention and times increase (Experiment 1B).

H4: Moving icon detection rates are higher than shape detection rates and detection times are shorter (Experiment 1B).

H5: Motion detection rates and times will not be significantly affected by distance (1A and 1B).

H6: Smaller motions lead to lower detection rates and longer detection times (1A and 1B).

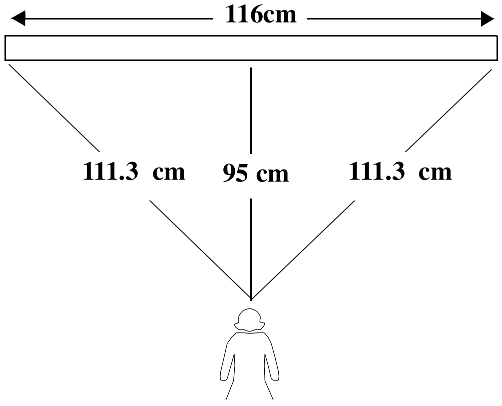
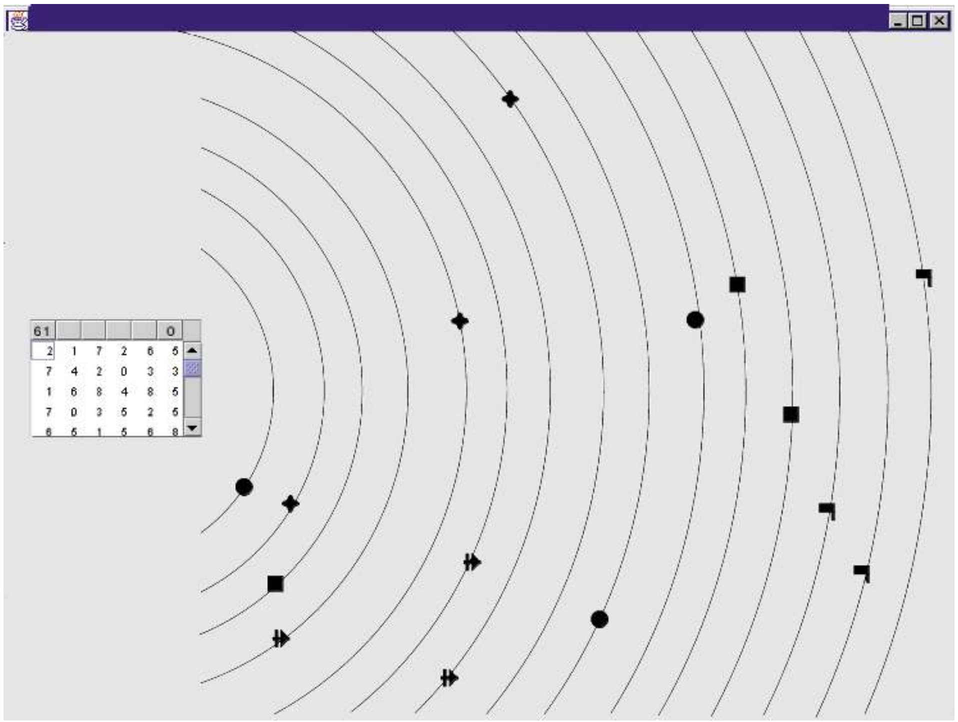


Figure 1. Subject position and screen width

Most of the method was the same for 1A and 1B. We describe this common method first.

Screen layout



61					0
2	1	7	2	6	5
7	4	2	0	3	3
1	6	8	4	8	5
7	0	3	5	2	5
6	6	1	5	6	8

Figure 2. One trial of Experiment 1A. The arcs were **not** displayed.

A wide rear-projected screen was used. The dimensions of the projector screen were 116 cm x 87 cm. The resolution of the screen was 800 x 600 pixels which translated to approximately 145 mm/pixel. The subject was seated in front of the screen at 95 cm as illustrated in Figure 1. The primary task area of approximately 11.6 cm was placed at either the left or the right of the stimulus window such that it was vertically centred and had a horizontal margin on each side of roughly 2.9 cm. Figure 2 shows one screen layout with the primary task located on the left. The range of stimulus positions subtended a field of view from approximately 7 to 52 degrees of visual angle from the centre of the primary task window.

The screen was located in a graduate research lab and the overhead fluorescent lights were dimmed for the experiment. No other special considerations were applied, so that subjects were often doing the experiment while other work was going on the lab with normal (moderately quiet) noise levels.

Figure 2 illustrates the screen layout.

Primary Task

Subjects were asked to carry out a simple editing task in a window which was located either to the left or the right on a larger window (see Figure 2). The small window contained a scrollable table of numbers from 0 to 9 and the subject was instructed to find all the 0s in the table and replace them with 1s. A static counter in the upper left hand corner showed the total number of 0s in the table; a running counter in the upper right hand corner indicated the number of 0s currently found and replaced by the subject. Subjects could use the arrow keys and/or the mouse and scrollbar to navigate through the table.

Secondary Task

The larger window contained 15 icons, of which one might change according to one of the cues (motion, colour or shape). In a fifth of the trials nothing would happen. Upon detecting a change subjects were instructed to hit the CONTROL key, thereby ending the trial. Each of the 15 icons was randomly positioned on an arc at fixed radial distance from the centre of the task window, as illustrated in Figure 2. Icons were positioned in near and far conditions such that the NEAR targets were positioned on arcs 1-5 and the FAR targets were positioned on arcs 11-15. The NEAR targets subtended a field from approximately 7 to 20 degrees of visual angle, while the FAR targets subtended a field from approximately 40 to 52 degrees of visual angle. The target was randomly determined for each trial from the respective set of 5 icons. None of the icons on the arc 6 through 10 was ever a target. Each icon was bounded by a rectangle of 2 cm x 2 cm. This corresponded to roughly one degree of visual angle at the viewing distances we used.

Cue onset occurred between 5 to 20 seconds after the trial started. Cue onset was randomly selected from this 15 second range for each trial. Each cue lasted 5 seconds. If no detection was indicated the trial timed out after 30 seconds.

Experiment Subjects: 12 SFU students in either Computing Science or Psychology participated in the study. There were 6 males and 6 females. None were colour-blind although 5 wore glasses. Subjects were paid to participate.

Experiment Conditions

The 4 (cue type) x 2 (distance) factor design produced 8 cue conditions. An additional 2 no cue (NO_CUE) control conditions were added resulting in 10 conditions overall. Thus in 20% of the trials nothing happened and the trial timed out. A trial block contained 2 repetitions of each condition for a total of 20 trials. The ordering of conditions was randomized within a block independently for each subject. Trials were combined into 4 blocks of 20 trials each. Blocks were repeated 4 times totalling 80 trials per subject.

The task position was counter-balanced for left and right position and changed with each block. An equal number of subjects started with the task in the left position and in the right position. Each block was subject-initiated, so that subjects could pause between blocks if desired.

All subjects were given a training block of 10 trials with all cues before each study so that the subject was comfortable with the primary task and had seen all cues before the experiment.

Motion cues

There were two motion conditions. In the high amplitude condition (HIGH_AMP) the icon moved smoothly up and down along a path its own height (2 cm) with sinusoidal motion, a dis-

Figure 0-1. Icon shapes used in Experiment 1A

tance which covered approximately one degree of visual angle. In the low amplitude motion (LOW_AMP) the path length was the half the height of the icon (1 cm) or approximately half a degree of visual angle. Frequency was roughly 3 Hz.

Experiment 1A: Colour vs. motion

Method

In Experiment 1A two colour signals were evaluated together with the two motion signals. 6 icon shapes were used and all were initially coloured black. Icon shapes were randomly assigned on each trial from a set of 6 canonical shapes shown in Figure 0-1. The colour signals were a colour change to RED (RGB 255,0,0) or GREEN (RGB 0,255,0).

Results: Experiment 1A

The results from experiment 1A are summarized in Figures 3 and 4 showing detection error rates and detection times respectively. Detection times were faster with the moving icons and error rates were lower (H2). A multiway analysis of variance showed both cue and location

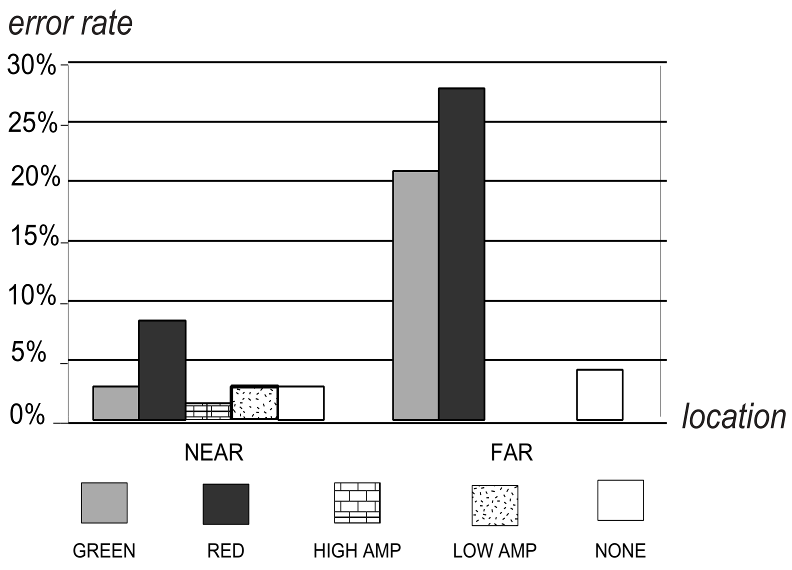


Figure 3. Mean detection error rates: colour vs. motion (Experiment 1A)

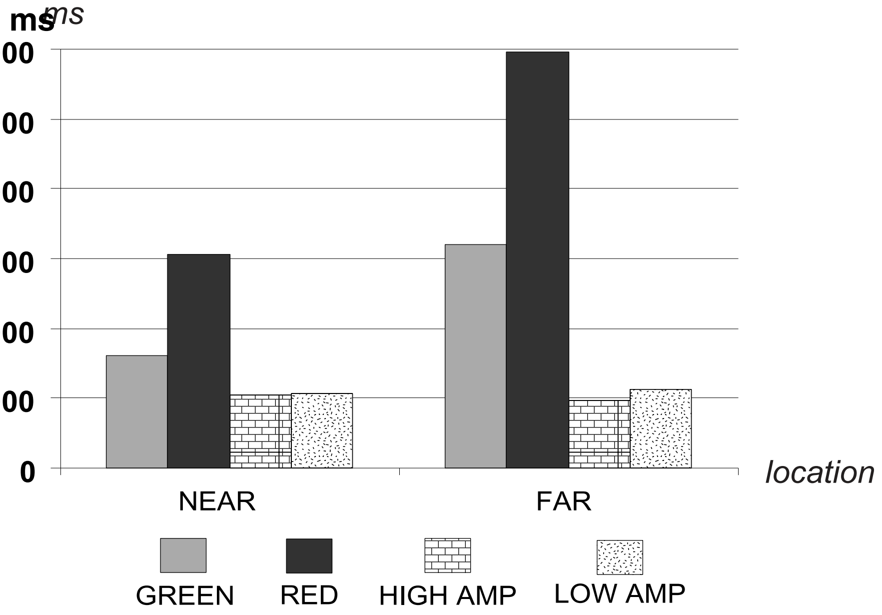


Figure 4. Mean detection times: colour vs. motion (Experiment 1A)

effects to be highly significant for detection rates: cue was F(4,48)=14.098, p<.0001; location was F(1,12)=14.846, p<.0002. As we expected there was a significant interaction between cue and location: F(4,48)=7.304, p<.0001. The moving icons were equally well detected in both the near and far visual field (H5). There was nearly a 100% detection rate for motion in both the near and far condition. However, as predicted (H1,H5), colour detection fell off in the periphery for both red and green icons, while motion remained constant. The average error rate for colour was 5.5% in the near condition and 24% in the far condition.

The difference between colour and motion is also evident in the detection times shown in Figure 4. Again, cue and location were significant effects: cue F(4,48) = 40.278, p<.0001; and location F(1,12) = 7.135, p<.01, confirming our hypotheses (H1,H2,H5). All of the detection times for motion were around 1 second but the detection times for colour averaged 2.3 second in the near condition and 4.6 seconds in the far condition. Again, the interaction between cue and location was significant: F(4,48) = 2.695, p<.05). There was no effect of motion amplitude on detection rate or time, contrary to our hypothesis (H6).

Experiment 1B: Shape vs. motion

Method

In Experiment 1B two shape-change signals were compared to the two motion signals from Experiment 1A. In this experiment, all the icons had the same circular shape but colour varied. Icon colour was randomly assigned from a set of 6 RGB colours: red (255,0,0), green (0,255,0), blue(0,0,255), cyan(0,255,255), yellow (255,255,0), white (255,255,255) or black(0,0,0). The two shape cues were an X and an upright flag shape (Figure 5).

Figure 5. Icon shapes used in Experiment 1B

Results: Experiment 1B

The pattern of result for shape is very similar to that obtained for colour and is summarized in Figures 6 and 7. As predicted, the moving icons had higher detection rates and overall faster detection times than the shape cues (H4). As in Experiment 1A, both cue and location have highly significant effects on detection: cue F(4,48)=13.19, p<.0001; and location F(1,12)=15.92, p<.0001. While motion has a constant detection rate in the near and far locations (H5), the detection rate for the two shape cues falls off in the periphery (H2) and this interaction between cue and location is statistically significant (F(4,48)=7.37, p<.0001.

Again, cue and location had strong effects on detection times: cue F(4,48)=19.55, p<.0001; and location F(1,12)=31.33, p<.0001. The interaction between cue and location is also statistically significant (F(4,48)=4.66, p<.05. The detection time results (Figure 7) showed a large near far difference for shape but not for the high amplitude motion condition, increasing from 2.0 seconds to 4.4 seconds, while times for that motion type remained constant at about 1.0 seconds. Interestingly, there is a location effect in this experiment for the low amplitude motion: detection

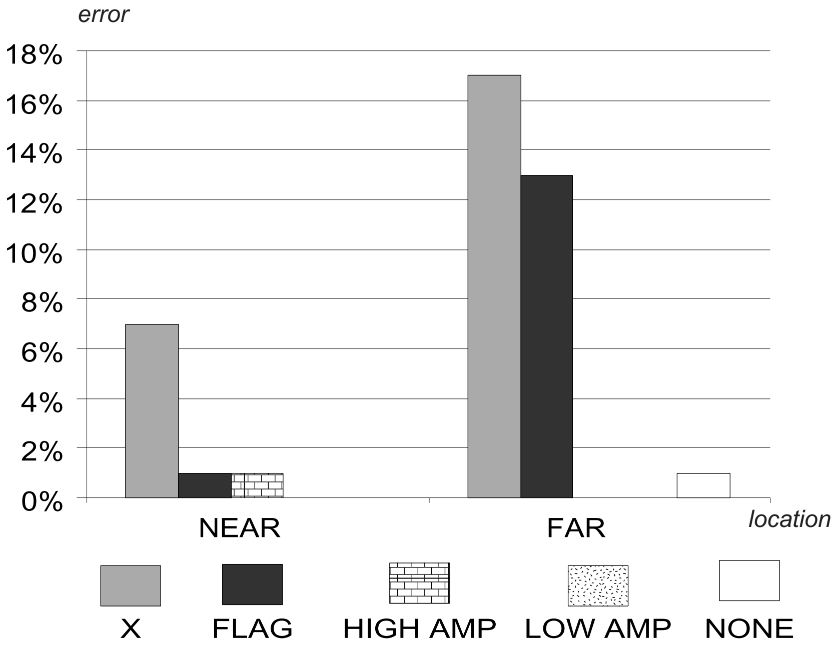


Figure 6. Mean detection error rates: shape vs. motion (Experiment 1B)

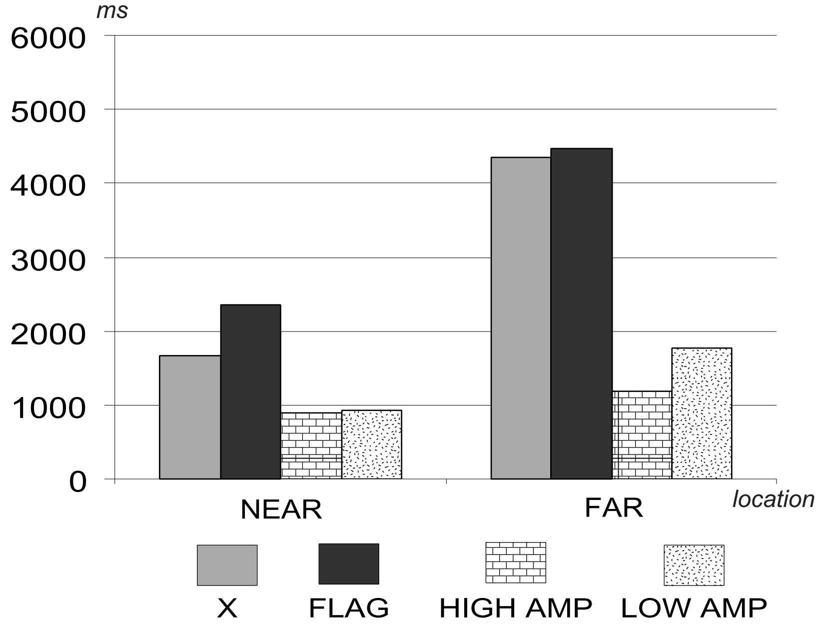


Figure 7. Mean detection times: shape vs. motion (Experiment 1B)

time almost doubles in the far condition, from.92 s to 1.78 s. (which is still only about 40% of the shape detection times.) This partially confirms our expectation (H6), but it only occurs in the far condition in this experiment. As both experiments (1A and 1B) were performed by a subject in a single session, and as experiment ordering was counter-balanced, this result is puzzling. Two possible explanations relate to speed and distance. The LOW_AMP motion moves more slowly than the HIGH_AMP motion, as it covers half the distance in the same amount of frames. Ware et. al have shown that faster movements provoke quicker responses (Ware et al. 1992). Another reason may be that there is a distance threshold an object has to exceed before it is perceived as moving. It is conceivable that these properties have greater influence over the detection of motion in the periphery than in the central area of vision.

Discussion: Experiment 1

The results of Experiment 1 show that even relatively slow motion is more effective than either colour or shape change in attracting user attention, especially in the periphery of the visual field. Our expectation that motion amplitude would affect detection accuracy was not supported: there was no significant difference in either experiment between the two motions. However, detection times were influenced by motion amplitude, but only in Experiment 1B in the far condition. As both experiments (1A and 1B) were performed by a subject in a single session, and as experiment ordering was counter-balanced, this result is puzzling. Two possible explanations relate to speed and distance. The LOW_AMP motion moves more slowly than the HIGH_AMP motion, as it covers half the distance in the same amount of frames. Ware et. al have shown that faster movements provoke quicker responses (Ware et al. 1992). Another reason may be that there is a distance threshold an object has to exceed before it is perceived as moving. It is conceivable that these properties have greater influence over the detection of motion in the periphery than in the central area of vision. Nonetheless this effect was still substantially below the detection times of the static cues. This indicates that very small linear oscillations of limited duration are appropriate notification mechanisms in a dense display environment.

Experiment 2: Cue Identification in a Heterogeneous Environment

Experiment 1 demonstrated the efficacy of oscillating motion as a signal in simple displays with only a few variables (motion and shape or colour). In the real world, however, displays are crowded with multiple colours and shapes. A signal must not only alert the user to some event; it must also be immediately identifiable, so that the user knows which visual element on the screen changed and thus which event the signal represents. We adapted the previous experiment method to a more ecologically valid approach to simulate the environments we see today, in which colour and shape are combined, and in which change requires the user to not only recognize that something has happened but also to find the relevant object.

Method

Experiment 2 combined colour, shape and motion cues to investigate how well they performed in a more complex screen in both detection and identification: i.e., how accurately the subject could find which icon in the visual field had changed. In addition, four distinct motion types were investigated, of different shapes and smoothness (continuity). Accuracy and response time in both detection and identification were measured. Specifically, it extended the approach used in Experiment 1 in the following ways:

- In Experiment 1A, the icons varied in shape but were all initially of the same colour. In Experiment 1B, the icons varied in colour but were all initially the same shape. Experiment 2 icons varied in both colour and shape.

- In Experiment 1, the only secondary task was detection: all the subject had to do was indicate he or she had seen the cue. Experiment 2 required the subject to both indicate detection and to identify (by pointing at it with the mouse) the icon that had changed.

- Experiment 1 had only two dependent variables: detection error and detection response time. Experiment 2 measured four dependent variables: detection error, detection time, identification error and identification time.

We expected motion detection to outperform the colour and shape cues as in Experiment 1. We had the same detection hypotheses as Experiment 1. In addition, we considered different smoothness conditions to test the following hypothesis:

H1: Motion smoothness affects detection.

We also anticipated that identification would be faster and more accurate with the motion cues. Specifically we had the following hypotheses related to identification:

H2: Identification is more accurate with motion than with colour or shape.

H3: Colour and shape identification accuracy decreases with distance.

H4: Motion identification accuracy will not be affected by distance.

H5: Motion identification times are faster than colour or shape.

Screen Layout

The same screen layout and task window as in Experiment 1 were used. The screen contained 15 icons to which the shapes of Experiment 1A (Figure 0-1) and the colours of Experiment 1B were randomly assigned. Icon size, placement and NEAR/FAR assignment were handled as in the previous experiment. Green (0,255,0) and the X shape were reserved for cues.

Experiment Tasks: Primary and Secondary

As in Experiment 1, the primary task consisted of editing a table of numbers to replace 0s with 1s. The secondary task consisted of a detection and an identification stage. In the first stage, the subject performed the editing task and was instructed to hit the CONTROL key upon detecting any change. In 25% of the trials no change occurred. Cue onset occurred at some time between 5 to 20 seconds after the trial started and lasted for 5 seconds. Onset was randomly selected from this 15 second envelope for each trial. Indicating detection ended this stage of the trial. If no cue was detected, this stage timed out after 30 seconds. Thus if there was no cue and this stage of the trial timed out, detection was logged as TRUE. The timing envelope ensured a buffer of at least 5 seconds between when the cue stopped and when the subject was prompted to identify it.

At the end of the detection stage a prompt appeared over the task table instructing the subject to identify the changed stimulus using the mouse or to indicate "no change" with CONTROL. The identification stage was not time-constrained. Completing the identification task ended the trial.

Cues

6 signals were used as cues: a colour change, a shape change and 4 motion types. An icon could change to GREEN or change shape to an X. Alternately, it could move according to one of 2 shapes and one of two smoothness conditions, as follows:

- SMOOTH LINEAR: Similar to Experiment 1, the icon moved smoothly up and down a path its own height (14 pixels) with sinusoidal motion (henceforth, *smooth* will refer to sinusoidal motion).
- JUMPY LINEAR: The icon moved up the same linear path smoothly and then "jumped" in one frame back to the starting point.
- SMOOTH ZOOM: The icon smoothly grew and shrank between 100% and 200% of its original size, centered on its origin.
- JUMPY ZOOM: The icon smoothly grew to 200% of its original size and then "jumped" in one frame back to its starting size. This gave the impression of "popping out".

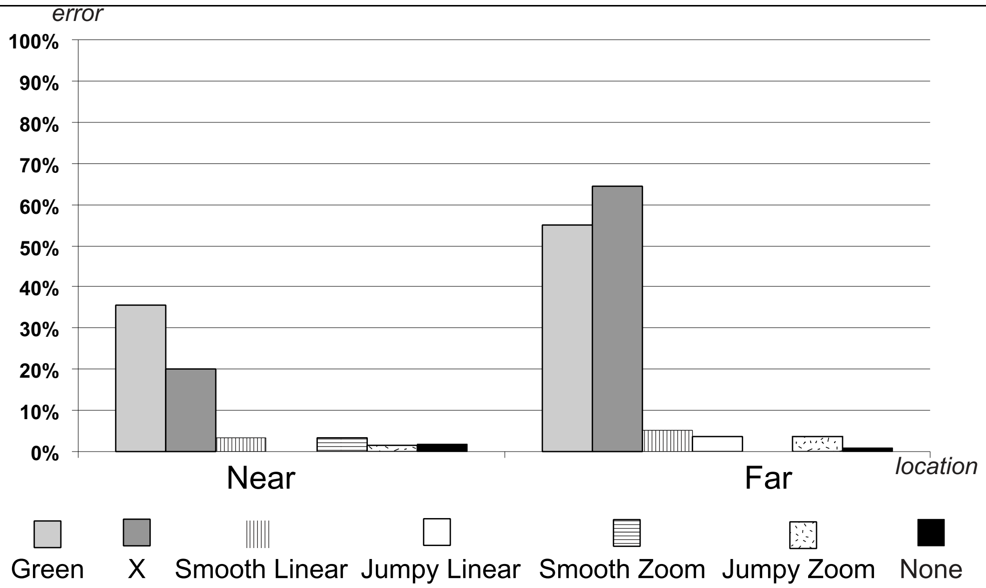


Figure 8. Experiment 2 mean detection error rates

Experiment Conditions

Adding two NO_CUE conditions to these 6 cues gave an 8 (cues) x 2 (location) design, resulting in 16 conditions of which each subject performed 5 repetitions, totalling 80 trials per subject. Condition ordering was independently randomized for each subject. over the entire 80 trials. Trials were grouped into blocks of 20. As in the previous experiment, task position was counter-balanced for left and right position and changed with each block. An equal number of subjects started with the task in the left and right position. Each block was subject-initiated. All subjects were given a training block with 16 trials covering all cue types before each study and could practise with it until the subject was comfortable with the primary task and familiar with all cues before the experiment.

12 SFU students in either Computing Science, Psychology or Kinesiology participated in the study. None were colour-blind although 4 wore glasses. Subjects were paid to participate.

Results and Discussion: Experiment 2

Detection error rates and times are shown in Figures 8 and 9 respectively. Similar to Experiment 1, detection error rates were lower with the moving icons. In this experiment, the moving icons significantly outperformed the static cues in both the NEAR and FAR fields (F(6,72)=72.76, p<.0001). This was to be expected given that the colour and shape coding dimensions were already “crowded”. However, as assigning colour and shape to signals is a common approach in information-rich displays, it is noteworthy how poorly they perform. Location was also significant (F(1,12)=22.67, p<.0001). However, there was again a significant interaction

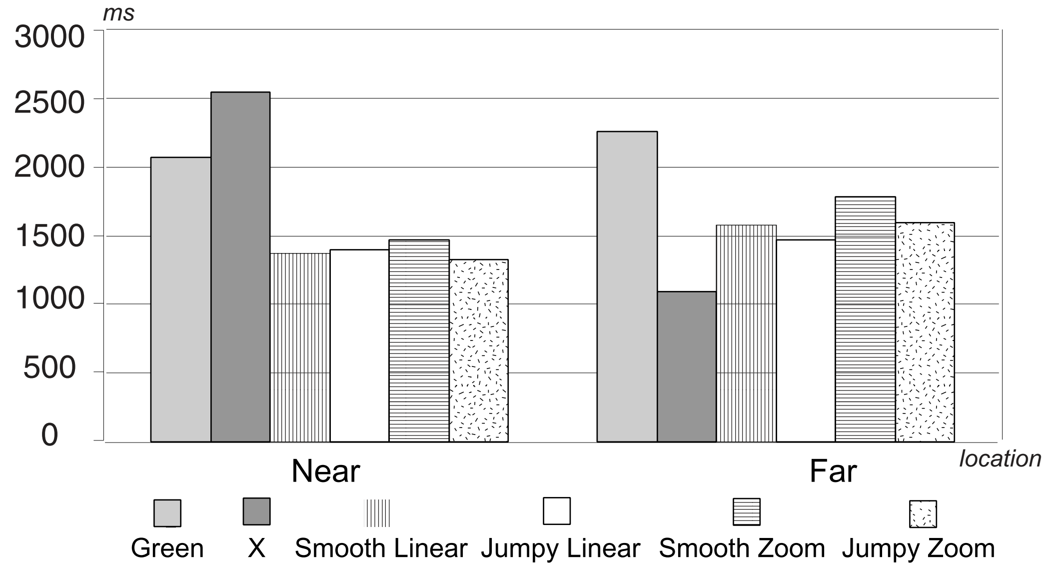


Figure 9. Experiment 2 mean detection times

between cue and location (F(7,84)=12.84, p<.0001). Location had no effect on the detection accuracy for any of the moving cues, while detection of the static cues fell off dramatically in the periphery.

Cue had a main effect on detection time (F(5,60)=29.52, p<.0001). There was no main effect for location, but there was a significant interaction with cue: F(5,60)=4.28, p<.001. The moving cues were more quickly detected than the static cues in the NEAR field and more quickly detected than the colour cue in the FAR. Interestingly, while the shape cue and colour cue had similar error rates in the far condition it took subjects substantially longer to detect the colour change. Contrary to our hypothesis (H1), the smoothness of the motion had no effect on the detection results. All of the motion cues performed equally well with no significant differences.

Figure 5-11 shows the mean identification error rates and Figure 5-12 the mean identification times. A multiway analysis of variance showed cue (F(5,60)=8.85, p<.0001) to have a highly significant effect on identification accuracy, while location had no effect and there was no interaction, contrary to our expectations regarding the static cues (H3) and confirming our prediction about the motion cues (H4). Accuracy in identifying the static cues was markedly poor (H2), especially for colour (almost 50% in the near condition and over 60% in the far condition). The identification times (Figure 5-12) show no significant effects and were all around 1.5 s, contrary to our hypothesis in H5. It must be noted that detection and identification times were, as in the previous experiments, measured across all responses and not just the correct ones.

Distraction and Detection in Different Task Conditions

While the detection results proved the strength of motion signals as notification mechanisms in a particular task environment, further questions arise concerning the effect on different

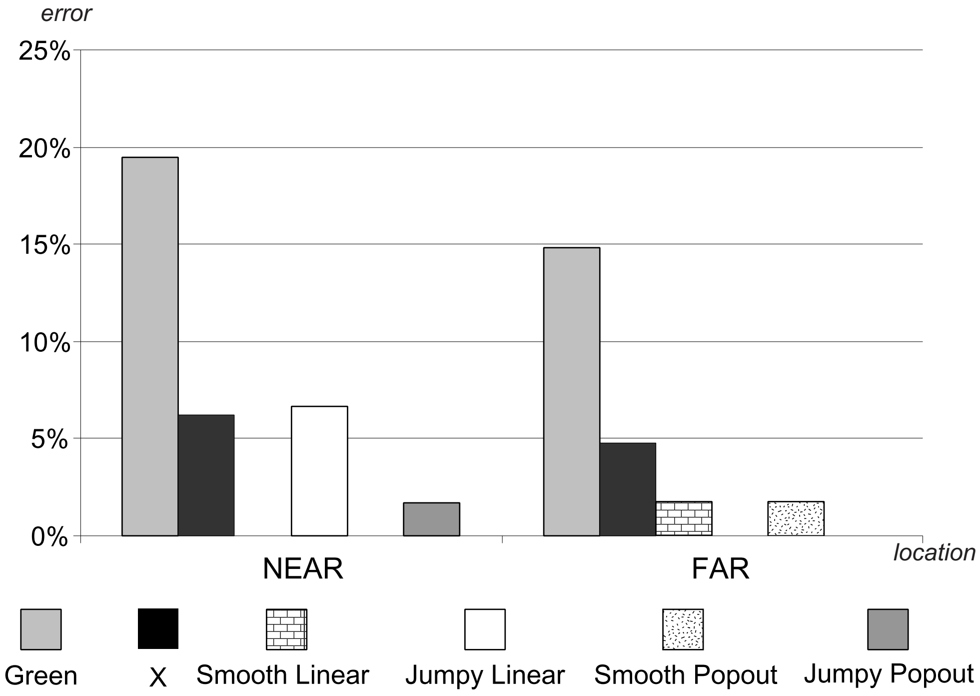


Figure 10. Experiment 2 mean identification error rates

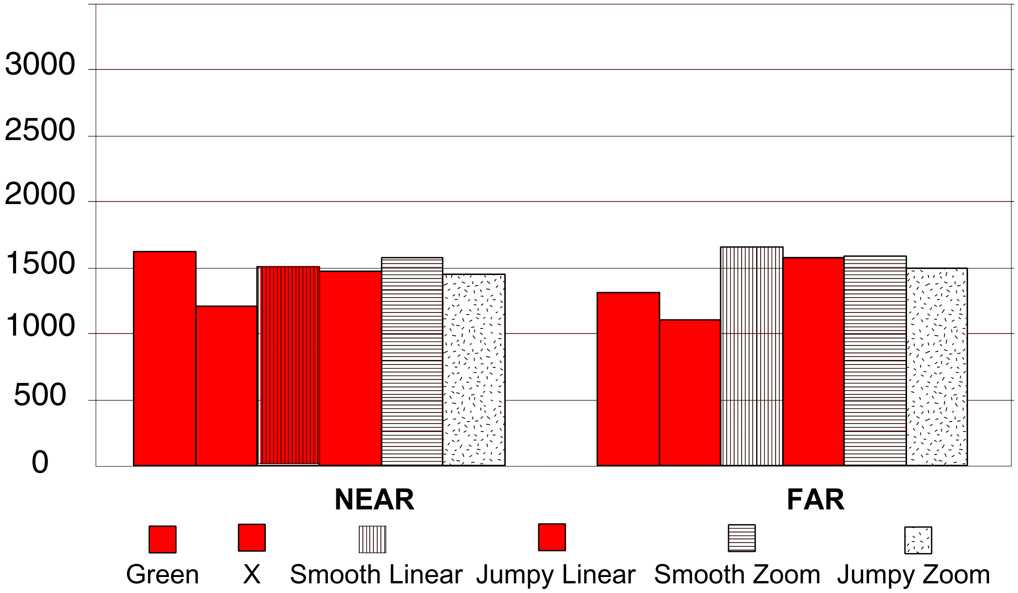


Figure 11. Experiment 2 mean identification times.

types of tasks. Our ability to see things at the edge of a computer screen may vary with our level of attention to the task we are performing. A "searchlight metaphor" has been used to model how attention falls off in the visual periphery as a function of the cognitive load or the stress level of an operator (Wickens 1992). A phenomenon known as *tunnel vision* occurs under conditions of very high stress, but even under relatively low stress conditions the focus of attention narrows considerably (Williams 1985). Focusing attention in a visually "noisy" field requires the user to maintain both control of where she is attending and awareness of potentially interesting areas as conditions change. While we believe that motion has great promise to support Woods' cognitive tools for managing attention (Woods 1995) the issues of attentional focus and distraction must be addressed.

Motion can be particularly distracting because the human visual system automatically tracks and predicts movement. We can track several moving objects in parallel (Pylyshyn et al. 1993). Hillstrom and Yantis (Hillstrom and Yantis 1994) suggest that it may not be motion per se that attracts attention, but rather the appearance of a new object in the visual field. These findings suggest that introducing extensive motion into user interfaces may be problematic. When a new object gains the attention of the tracking system, another object will typically be lost. This can lead to problems occurring with distracting irrelevant items. In particular, the moving banner animations on many web pages may be particularly distracting because they activate this tracking mechanism. In one study confirming the common complaints of distraction and task interference from such moving elements, Maglio studied both continuos and discrete, or sporadic, scrolling banners to assess how well the subject could execute a primary editing task while remaining aware of the information in the banner (the secondary monitoring task) (Maglio and Campbell 2000). They found that continuous scrolling was substantially more distracting (impeded the primary task) with no increased benefit in awareness of the information contained therein. Our intuition was that, while many types of motion are efficient in attracting and directing attention, certain types of motion are inherently more distracting than others. A related intuition was that this distraction factor would depend to a certain extent upon the nature of the task, following work by Czerwinski on how different types of search tasks are affected by interruption (Czerwinski et al. 2000). These latter researchers found that interruptions are more disruptive to faster, stimulus-driven tasks than to effortful, cognitively taxing tasks.

This study was designed to evaluate the detectability, distraction and irritation properties of different types of moticons in desktop environments under different task conditions. We chose three different tasks intended to require different kinds of user response and varying levels of attentional focus.

Experiment 3: Distraction, Detection and Task

This experiment compared how well subjects detected various types of motion cues and how distracting they considered them in various tasks requiring different degrees of concentration. The subject was engaged in a primary task in a window in the middle of the screen with icons distributed around the periphery of the monitor. During the task different moving cues occurred in random locations. The subject was instructed to indicate when the cue was noticed and later, in a post-task stage, to rate each of the cues for how distracting and irritating they were.

Three different primary tasks were designed to demand different levels and types of attentional focus. We were interested in wo questions:

1. are certain motion types more distracting than others? and
2. does the level of distraction differ with task type?

Detectability was measured by detection rate and time. Distraction and irritation were rated on separate 5-point Likert scales. We considered four motion types in two major categories: *anchored* and *traveling*. Anchored motions such as those used in the detection experiments described in the previous chapter are characterized by small trajectories around ("anchored on") the icon origin. Traveling motions involve larger trajectories in which the object leaves its original position and "travels" through several degrees of visual angle. Our intuition is that traveling motions demand more attention because there is a cognitive act of *tracking* involved in addition to detection. Thus the animated icons (moticons) commonly used as place markers on a WWW page would be considered anchored, while the scrolling tickertape banners would be considered traveling. We had six hypotheses.

H1: Detection errors, times and distraction ratings vary with task load (the most demanding task would show the lowest distraction rating and highest detection times);

H2: Detection accuracy is affected by motion type.

H3: Detection times are greater with slower motions and distraction is less;

H4: Detection times are less with traveling motions than with anchored motions; and

H5: Motion type has more effect on distraction than motion frequency.

H6: Traveling motions are more distracting than anchored motions.

Method

A dual-task design was used with different primary tasks and a secondary task of detecting moving icons. Subjects rated distraction and irritation aspects of the motion types in a post-task rating phase.

Screen Layout

The primary task was centred in a single full-screen window which was framed by a border of 32 icons. Icon shapes and colours were the same as those described in the detection experiments. Shape and colour were randomly set each trial but position was constant. Each icon was bounded by a rectangle of 16x16 pixels. A standard 21" monitor was used. Figure 0-1 shows one screen layout with the Solitaire task.

Primary Tasks

Three primary tasks were used: browsing and studying on-line text (TEXT), playing a variant of Solitaire called FreeCell (SOLITAIRE) and playing Tetris (TETRIS). In the text task, subjects

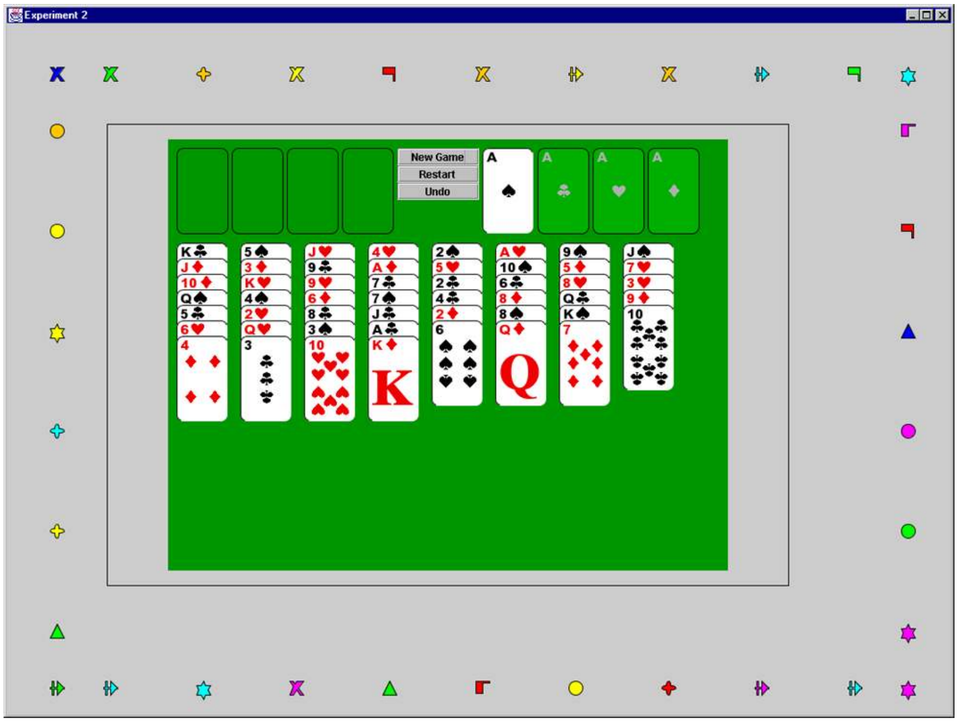


Figure 0-1. Experiment Screen with Solitaire task

were instructed to imagine that they had a class the next day in the particular subject and that they had to know this material before they went to class. Four different texts were selected to be outside the normal topic scope of the subject population. They dealt with the following areas: climate change due to methane gas production from farming in New Zealand (environment/agriculture); the history of the search for the tenth planet (astronomy); drug addiction treatment and management in Australia (social work); and the Roman-Carthaginian wars (history). Solitaire is a game in which the user can be quite involved but events are completely user-driven; diverting attention pauses the game. Tetris, on the other hand, is played against the machine in a stimulus-response type of interaction in which the user must intervene continuously; the game does not stop when the user does. We hypothesized that Tetris would be the most engaging task (command the most attention) and that the text task would be the least engaging.

Secondary Tasks: Detection and Rating

In the first phase of the trial subjects were instructed to simply indicate detection of a moving icon by hitting the CONTROL key. The icon did not stop moving upon the detection event. In the rating phase of the trial, subjects replayed a shorter version of each cue in random order and rated each on a 5-point Likert scale for each of the following four criteria: how distracting the motion was (DISTRACTION); how distracting it would it be if it persisted throughout a similar task(LONG DISTRACTION); how irritating it was (IRRITATION); and how irritating it would it be if persisted (LONG IRRITATION). Distraction was defined as how *attentionally demanding* the cue was: that is, how strongly the subject remained aware of the movement once it had been detected. Subjects were asked to rate the cue for these criteria with respect to type of task in the trial: i.e., if the subject had been playing Tetris in the trial, she was asked to rate any of the cues seen with respect to how much attention they had taken away from Tetris. Cue ordering was random and timing was subject-initiated: the next cue was only played when the subject had answered all the questions and requested the next cue.

Motion Cues

Four motion types (*shapes*) were used:

1. LINEAR, in which the icon moved smoothly up in a sinusoidal motion and then "jumped" back to the origin (similar to the JUMPY LINEAR cue of Experiment 3);
2. ZOOM, in which the icon zoomed smoothly from starting size to twice the starting size and then jumped back to the starting size;
3. BLINK, a standard on-off cycle; and
4. TRAVEL, in which the icon moved across the screen at a constant rate either from right to left (if the icon were in the top or bottom location) or from top to bottom (if the icon were in a left or right position), leaving the screen at one side and wrapping around to the other.

Each motion type was implemented in two frequencies: SLOW (30 frames/sec., roughly 1HZ) and FAST (15 frames/sec., roughly 2HZ), resulting in 8 distinct motion cues. Amplitude for the anchored motions was the same as Experiment 1, namely the stimulus size of 16 pixels.

Experiment Design

The experiment was divided into groups of blocks. A subject performed one task in each block. Blocks were organized into groups of 3 with each block containing one instance of each task. Each subject performed 12 blocks in a session: 4 groups of 3 blocks each. Task ordering was counter-balanced and each subject had one block group starting with each task type and one more randomly selected block group.

Each block comprised eight trials, one per motion type (or *cue*). Thus each subject saw each cue in a given task condition 4 times.

Fourteen students from Psychology, Engineering, Computer Science and Kinesiology at SFU served as subjects. There were an equal number of males and females. None were colour-blind. Subjects were paid to participate.

Block and Trial Description

Each block consisted of two phases: the trial phase and the rating phase. In the trial phase the subject engaged in one of three primary tasks for a period of 4.5 minutes. During this phase there were 8 trials, one for each motion cue. Cue duration was 10 seconds. Trial timing was evenly distributed across 8 30-second "envelopes" with a randomized onset in each envelope from 5 to 15 seconds, such that the effect was random but no cues occurred less than 10 seconds or more than 30 seconds apart. Since there is evidence that interruptions are more distracting in the beginning stages of a task than when the task is well underway (Czerwinski et al. 2000), this even distribution avoided any task timing effect. Cue-icon assignment was also random but evenly distributed such that there were always two cues from each of the top, left, bottom and right sides. No icon was used twice in a trial. Subjects were instructed to concentrate on the primary task and to indicate detection by hitting the CONTROL key when they noticed any one of the eight cues. Cue detection did **not** stop the cue nor end the task, but it did end the trial. Trials were transparent to the subject, since he or she interacted continuously with the task until the entire block of trials had run.

When the trial stage of the block ended (by timing out), the subject was presented with a rating screen in which a single icon unique to the rating phase appeared in the upper left corner and a rating panel appeared in the centre of the window. Each motion cue was then briefly replayed and rated by the subject.

Experiment 3: Results and Discussion

Figures 12 to 14 summarise the detection results of this experiment. As predicted in the first hypothesis (H1), there was a significant task effect on detection errors (Figure 12), although the differences between the two game tasks were smaller than anticipated. Generally cues were most accurately detected in the text browsing task, which was hypothesised to be the least engaging of the tasks and therefore the most prone to distractors. The two games had similar results with Tetris showing a slightly higher rate of detection errors overall except for the FAST BLINK and SLOW ZOOM cues, suggesting that subjects were devoting more attention to Solitaire, which ran counter to our expectations. The SLOW BLINK was the least detected in all tasks with the odd exception of the FAST BLINK in Solitaire. An analysis of variance showed significant effects on detection

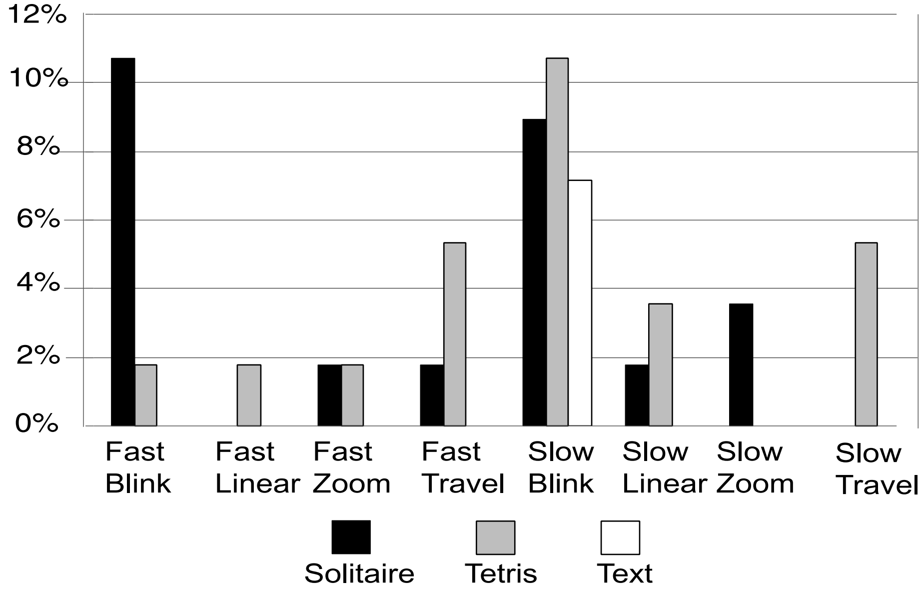


Figure 12. Cue detection error rates by task

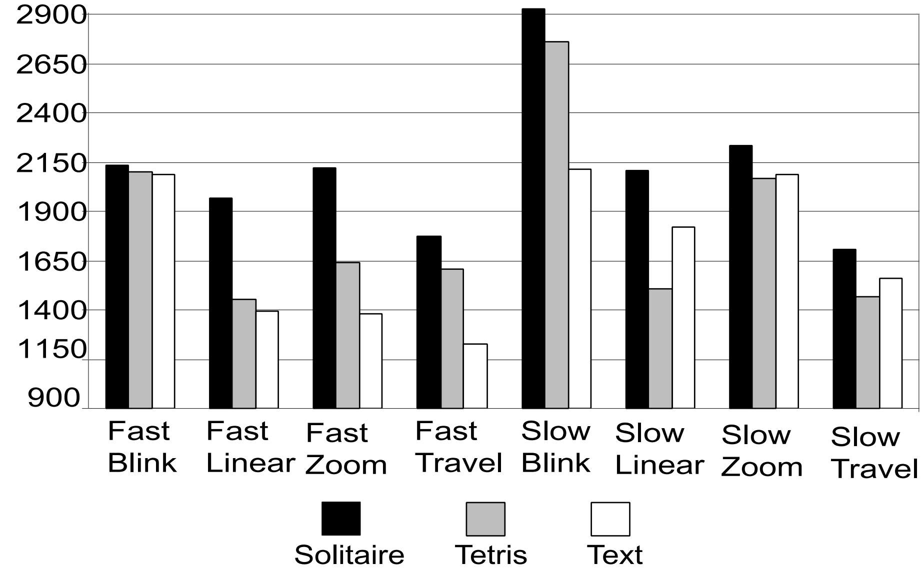


Figure 13. Cue detection times by task

	Fast Blink	Fast Linear	Fast ZOOM	Fast Travel	Slow Blink	Slow Linear	Slow ZOOM	Slow Travel
Fast Blink	▨							
Fast Linear	■	▨			✦✛■		■	
Fast ZOOM	■		▨		✛■		■	
Fast Travel	■			▨	✦✛■		■	
Slow Blink					▨			
Slow Linear					✛	▨		
Slow ZOOM							▨	
SlowTravel					✦✛			▨
✦: Solitaire ✛: Tetris ■: Text								

Figure 14. Pairwise comparisons of detection times: a task symbol in a cell indicates that the row cue had a faster (i.e. less) detection time than the column cue.

---

for cue type (F(7,84) =3.84, p<.001) and task (F(2,24)=4.75, p<.0001). There were no significant interactions. There was, however, a significant subject-task interaction for detection (F(2,26)=2.82, p<.0001). Two subjects detected less cues in Tetris than in Solitaire, where other subjects saw fewer in Solitaire than in Tetris. This may indicate the differing levels of engagement in the two games for different people. Detection for all subjects was more accurate in the text task.

With one notable exception (the FAST BLINK in Solitaire) these results match our expectations that task engagement and cue type together affect detection (H1, H2). The slow blink cue is the least well detected. Frequency alone has no effect on error rate. Instead the shape of motion overweighs frequency (FAST LINEAR, for example, is not better than SLOW ZOOM.) However, the BLINK, LINEAR and TRAVEL cues were less well detected in Tetris than the ZOOM motions, suggesting some interference with the motions already present in the task. The lower rate of detection for the FAST BLINK in Solitaire is mysterious.

Figures 13 and 14 show the detection time results. Overall, linearly moving cues (LINEAR and TRAVEL) were detected most efficiently. Analyses of variance in detection time show task (F(2,22)=4.75, p<.0001) and cue (F(7,84)=3.84, p<.001) effects to be highly significant, but this is mainly due to the slow detection of the SLOW BLINK cue, and does not clearly support our hypothesis that traveling motions would be detected more quickly than anchored motions (H4).

We hypothesised the fast cues would be more quickly detected than the slower cues (H3), but pairwise comparisons of significant differences in cue detection times by task from a post-hoc Tukey analysis (Table 14) failed to support this except for the slow blink cue, which had a much greater failure-to-detect rate. Task plays a large part in determining how relatively efficiently cues are detected: in particular, the differences between many cues are less pronounced in the two games tasks than in the text condition. Detection was fastest in the text task and slowest in Solitaire. Again these results emphasise that the detection of the various cues is dependent on the level of engagement in the task, or the task attentional load, and suggest that a measure of detection may be used with similar cues to gauge a user's involvement in a particular task.

Distraction Ratings

Figures 15 to 17 summarise the distraction results. There were only minor differences between the four subjective ratings (DISTRACTION, LONG DISTRACTION, IRRITATION and LONG IRRITATION): therefore we only report distraction. Generally, subjects rated the cues as increasing somewhat in distraction and irritation for longer persistence, but this was not a statistically significant difference. All three variables had significant effects on distraction ratings: task (F(2,24)=14.62, p<.0001); motion type (F(7,84)=86.89, p<.0001); and frequency (F(1,12)=40.18, p<.0001).

As evidenced in Figure 15, motion type, rather than motion frequency, clearly is the dominant factor: it has the most pronounced effect on distraction rating (H5). Blinking is rated as the least distracting, followed by linear, zooming and finally traveling trajectories. Although some subjects reported that their judgement of what was distracting changed as the experiment session progressed, there was no indication that when a trial occurred had any effect on the results. While task also had a significant effect, the magnitude of the difference was smaller than anticipated. As expected, cues were generally seen as more distracting in the text task than in the two game tasks, reinforcing the hypothesis that task engagement can be linked to cue distraction (H1). Frequency also influenced distraction rating as shown in Figures 16 and 17. Again, however, while the difference was constant, the magnitude was relatively small. Fast linear motion in Tetris is rated as more distracting than in Solitaire, suggesting that there may be issues of perceptual interference between cue motion cues and game motion. This demands further study.

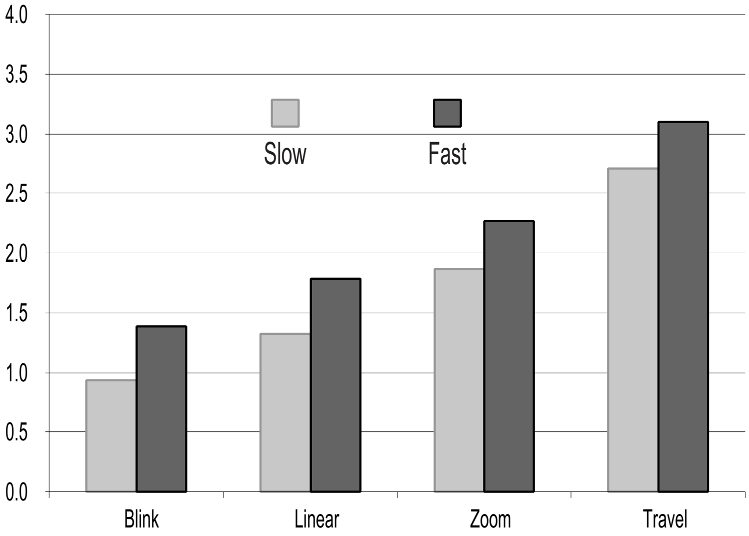


Figure 15. Distraction rating by type and frequency

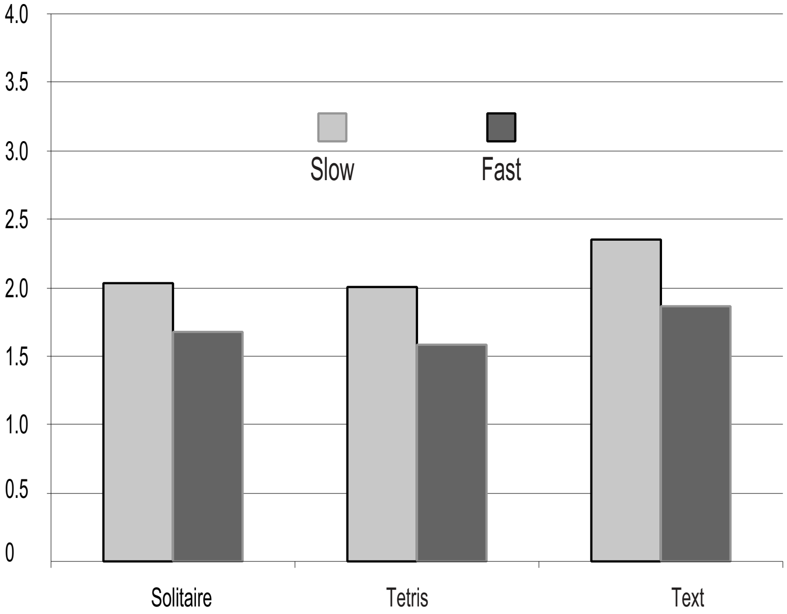


Figure 16. Distraction rating by task and frequency

There was a subject-task interaction for distraction rating (F(22,242) = 5.3984, p<.0001). We believe this was largely due to differences in performance and experience with the two games. However, there was also a subject-cue interaction (F(2,26)=2.904, p<.0001), which we believe is due to the fact that the 5-point scale is a relative measure. In this case it is more revealing to consider significant differences in cue distraction ratings from a Tukey pairwise comparison (Figure 17). From this it is immediately apparent that the two traveling cues are by far the most distract-

	Fast Blink	**Fast Linear**	**Fast Zoom**	**Fast Travel**	**Slow Blink**	**Slow Linear**	**Slow Zoom**	**Slow Travel**
Fast Blink	▨	■	✦✢■	✦✢■				✦✢■
Fast Linear		▨	✦	✦✢■				✦✢■
Fast Zoom			▨	✦✢■				✦
Fast Travel				▨				
Slow Blink		✦✢■	✦✢■	✦✢■	▨		✦✢■	✦✢■
Slow Linear			✦✢■	✦✢■		▨	✦	✦✢■
Slow Zoom				✦✢■			▨	✦✢■
Slow Travel								▨

✦: Solitaire ✢: Tetris ■: Text

Figure 17. Pairwise comparisons of distraction ratings: when a task symbol appears in a cell, the row cue is less distracting than the column cue.

ing, confirming our hypothesis (H6). The ZOOM cues, especially the fast, were considered the next most distracting. On the other hand, the SLOW BLINK and SLOW LINEAR cues were rated as the least distracting.

Conclusions and Discussion

These findings have a number of implications for the use of moticons as signals in human-computer interfaces. They suggest that motion has several advantages as a notification mechanism. It is significantly better than the traditional static codes of colour and shape in designing icons used to attract a user's attention, especially in the periphery. Our results showed that the percentage of undetected targets increased dramatically from 6% to 25% with the peripheral colour targets, whereas the failure-to-detect with motion was less than 2% in both the near and far field. Identification of the moving target was also substantially better with the moving cues than with the static cues across the entire visual field. These results once more emphasise the effect that location has on static and moving cues. Motion seems to be equally efficiently "remembered" in both near and far conditions, while colour and shape are less well noticed and less accurately tracked. The poor performance of the colour and shape cues even in the very sparse experimental displays is particularly noteworthy, as these cues are the most commonly used signals in current computing environments. In complex visualization and control systems where notification is of great importance, the poor detectability and identifiability of these cues argues for much more perceptually distinct signals. Even small, slow linear oscillations of the types reported here are excellent candidates for such notifiers. They have the advantage of being computationally cheap and consume little spatial and temporal resources. Perhaps the greatest advantage of using motion-based signals, however, is that they do not seem to interfere with existing colour and form coding, allowing extra information to be communicated through an object without changing its original codes which represent other variables.

The high rate of detection even in the more attentionally demanding tasks suggests that motion is effective over a wide range of locations, types and amplitudes. Even the least efficiently detected cue, the slow blink, had a worst-case mean response time of less than 3 seconds and was detected 89% of the time within the 10-second window, indicating good accessibility even when the primary task is demanding.

However, we did find differences in the ease with which people could be distracted from the primary task, although the results were not exactly what we anticipated. Although we had expected that Tetris would be the task most engaging of attention and our subjects anecdotally said that it was, the objective measures did not support this. Indeed the measured response times were longest for Solitaire, suggesting that this demanded the most attention. Our assumption that Tetris would demand more attention was obviously incorrect. Perhaps the reason for this lies in the different kind of cognitive attention required by the two games. While Tetris demands an immediate, against-the-clock reaction based on pattern-matching, Solitaire involves more think-ahead and "what-if" planning (since more of the consequences of a move are visible). Interestingly these results run somewhat counter to those of (Czerwinski et al. 2000a) in which cognitively effortful tasks are more disrupted by interruptions than faster stimulus-response tasks such as Tetris. Instead our findings indicate that detection was less accurate and slower in the effortful task of Solitaire. However, it must be emphasised that we did not measure primary task performance but instead signal recognition. In any case, our results show that even with highly demanding tasks motion can be readily used as an alert. They further suggest that such motion cues may be used to gauge task engagement.

Finally, while all the tested motions are effective as signalling mechanisms some are clearly more distracting to the user. Traveling motions which involve both detection and tracking are substantially more distracting than anchored motions. The zoom motions are also (although less) distracting, probably because they elicit sudden perceptual onset (Hillstrom and Yantis 1994). These findings confirm our experience that animated banners and popping images are not comfortable visual elements on a screen where one is trying to work but are effective if one in fact wants to dominate the user's attention. Overall the slow linear motion would appear to be a good compromise. It was rated among the least irritating and distracting but it elicited good response times and detection rates.

Acknowledgements

This research was carried out when the first author was at the School of Computing Science at Simon Fraser University and was partly supported by the Canadian Telelearning Network Centre of Excellence and by the Natural Sciences and Engineering Research Council of Canada.

References

ADAMS, M., TENNEY, Y., AND PEW, R. 1995. Situation awareness and the cognitive management of complex systems. *Human Factors 37,* 1, 85–104.

BAECKER, R. AND SMALL, I. 1990. Animation at the interface. In *The Art of Human-Computer Interface Design*, B. Laurel, Ed. Addison-Wesley, 251–267. taxonomy of animation uses in user interface.

CUTRELL, E., CZERWINSKI, M., AND HORVITZ, E. 2000. Instant messaging and interruption: Influence of task type on performance. In *OZCHI 2000 Conference Proceedings*, C. Paris, N. Ozkan, S. Howard, and S. Lu, Eds. 356–361.

CZERWINSKI, M., CUTRELL, E., AND HORVITZ, E. 2000b. Instant messaging and interruption: Influence of task type on performance. In *OZCHI 2000 Conference Proceedings*. 356–361.

CZERWINSKI, M., CUTRELL, E., AND HORVITZ, E. 2000a. Instant messaging: Effects of relevance and time. In *People and Computers XIV: Proceedings of HCI 2000, Vol.* British Computer Society, 71–76.

GILMORE, W., GERTMAN, D., AND BLACKMAN, H. 1989. *User-Computer Interfaces in Process Control: A Human Factors Engineering Handbook*. Academic Press, San Diego.

HEALEY, C., BOOTH, K., AND ENNS, J. 1995. Visualizing real-time multivariate data using preattentive processing. *ACM Transactions on Modeling and Computer Simulation 5,* 3, 190–221.

HILLSTROM, A. AND YANTIS, S. 1994. Visual attention and motion capture. *Perception and Psychophysics 55,* 4, 399–411.

MAGLIO, P. AND CAMPBELL, C. 2000. Tradeoffs in displaying peripheral information. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2000)*. ACM.

MCCRICKARD, D. S. 2000. Maintaining information awareness in a dynamic environment: Assessing animation as a communication mechanism. Ph.D. thesis, Georgia Institute of Technology.

MITCHELL, C. AND SUNDSTROM, G. 1997. Human interaction with complex systems: Design issues and research approaches. *IEEE Transactions on Systems, Man and Cybernetics 27,* 3 (May), 265–273.

PARSOWITH, S., FITZPATRICK, G., SEGALL, B., AND KAPLAN, S. 1998. Tickertape: Notification and communication in a single line. In *Asia Pacific Computer Human Interaction 1998 (APCHI '98)*. Kangawa, Japan.

PYLYSHYN, Z., BURKELL., J., FISHER, B., SEARS, C., SCHMIDT, W., AND TRICK, L. 1993. Multiple parallel access in visual attention. *Canadian Journal of Experimental Psychology.*

SARTER, N. AND WOODS, D. 1995. How in the world did we ever get into that mode? mode error and awareness in supervisory control. *Human Factors 37,* 1, 5–19.

SHNEIDERMAN, B. 1986. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. Addison-Wesley.

SMITH, G. AND ATCHISON, D. 1997. *Tthe Eye and Visual Optical Instruments*. Cambridge University Press, Cambridge, UK.

WARE, C. 2000. *Information Visualization: Perception for Design*. Morgan Kaufmann, New York.

WARE, C., BONNER, J., KNIGHT, W., AND CATER, R. 1992. Moving icons as a human interrupt. *International Journal of Human-Computer Interaction 4,* 4, 341–348.

WICKENS, C. 1992. *Engineering Psychology and Human Performance, 2nd. Ed.* Harper Collins, New York.

WILLIAMS, L. 1985. Tunnel vision induced by a foveal load manipulation. *Human Factors 27,* 2, 221–227.

WOODS, D. 1991. The cognitive engineering of problem representations. In *Human-Computer Interaction and Complex Systems*, G. Weir and J. Alty, Eds. Academic Press, 169–188.

WOODS, D. 1995. The alarm problem and directed attention in dynamic fault management. *Ergonomics*.

WYSZECKI, G. AND STILES, W. 1982. *Colour Science: Concepts and Methods, 2nd. Ed.* Wiley Interscience.