Effects of Alcohol, Aging, and Sleep Loss on Temporal Factors in Vision

J. A. Smither, R.S. Kennedy, N. E. Lane

Department of Psychology, University of Central Florida, Orlando, FL

RSK ASSESSMENTS, INC., Orlando, FL

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Abstract
Task analyses of driving generally list a number of visual activities that require switching perceptions between different visual images. Thus a driver must very rapidly and continuously shift attention to interact with changing elements in a dynamic visual scene. Typically, however, visual tests used for certification and renewal of driver licenses ignore the transient nature of seeing and use visual test stimuli presented for extended duration under static conditions. Furthermore, recent literature implies that disruption of visual performance due to alcohol ingestion and other stressors is greater for tests involving transient visual capabilities than for tests of static visual performance such as high and low contrast acuity. We believe that how these temporal visual factors are modified by alcohol and aging, and even how many temporal factors there might be, have not been investigated thoroughly. While considerable literature exists on temporal and spatio-temporal processing, transportable, standardized tests of such abilities have not been generally available. To this end, a portable computerized test battery of six temporal-acuity tests (saccadic accuracy, simultaneity, strobe, phi phenomenon, critical flicker frequency, and masking) was administered to participants in a series of interlocking studies. Reliabilities, effects of practice, and predictive validities are available for alcohol, aging, and sleep loss effects. Factor analyses from two of these studies (N=58 and N=45) suggested a consistent two-factor dimensionality for the battery. The application of these tests for driving safety is discussed and current plans for relating performance to simulated and real driving performance (i.e. accidents) is reported.

Introduction
The processing of much visual information in everyday life involves the rapid presentation of visual images that change over time. Yet, complete assessments of visual processing usually ignore its temporal nature and focus on the use of stimuli presented for extended duration under static conditions. When compared to traditional measures of visual acuity, measures of resolution for moving targets (e.g. saccadic accuracy, simultaneity, masking etc.) have shown remarkably stronger relationships with many stimulus and organismic variables and with many applied tasks in which motion perception is involved (e.g., driving, flying, sports, etc.). Motion perception measures have also been shown to be highly sensitive to stressors such as alcohol and sleep deprivation (Jones, Chronister, & Kennedy, 1998; Jones, Kennedy, Rugotzke, Drexler, &
Compton, 1998; Kennedy, Ritter, et al. 1996), and to individual differences such as age (Kennedy, Jentsch, & Smither, 2001; Kennedy, Ritter, et al. 1996).

Studies in neuroscience of vision (Livingstone & Hubel, 1987, 1988; Livingstone, 1988) suggest that fine spatial acuity is mediated through the parvocellular division of the lateral geniculate portion of the thalamus and these studies indicate that this pathway subserves the more spatially precise visual capabilities which benefit from sustained inspection of visual information. On the other hand, there are visual psychophysical functions such as motion, depth perception, and flicker which operate much faster, and are subserved by a transient visual system. These latter functions appear to be carried by the larger, anatomically distinct, magnocellular division of the geniculo-cortical pathway. Not only do separate pathways imply a two-process (or multiple channel) theory of function (e.g., Regan, 1982) but logically, if individual behavioral sensitivities are found in one division they may be little correlated with sensitivities found in the other and both may be involved to a greater or lesser degree in processing many tasks. Thus, there is a need to systematically examine the temporal factors involved in perception of motion within the visual system. This important motion detection component of the visual system is critically involved in such temporal domains as visual perception of motion, maintaining smooth pursuit eye movements for visual targets, and extracting moving forms from static backgrounds.

So far as we know, temporal factors in vision are not tests per se in certification and renewal of driver licenses, nor in testing for other visually-demanding tasks. Relatedly, transportable and standardized tests of these abilities have not been generally available for use in clinical, commercial, military or other applications. To this end, we developed a battery of computer-based tests that characterize the motion perception capabilities of an individual. The tests were administered to participants in a series of interlocking studies where the effects of alcohol, age, and lack of sleep were investigated.

Methods

Test Selection and Development. Based on past literature (Sperling, 1960), it appeared that there were four important factors which made up temporal properties. Based on these factors, we selected tests according to how well they fit the following criteria:

1. Most visual stimuli are modulated in time, and most events have a duration. When events occur in succession, we are often able to distinguish them. Since the environment has a temporal dimension, the visual system must be able to represent and respond to it.
2. Temporal modulation is imposed upon the stimuli by the movement of our eyes over the environment.
3. Perception itself takes time. To understand the perception of temporal events we must know how long it takes the visual system to respond.
4. Temporal processing is important because the visual system is easily overloaded with both spatial and temporal information. Therefore, in addition to the need for the reduction of spatial information, temporal coding of information must occur in order to make perceptual processing manageable.
5. A fifth and powerful factor in applied writings (Regan, 2000) is that motion can cause image separation by means of parallax and segregate hidden or embedded objects due to disparate relative motion.
In contrast to an approach that is driven PRIMARILY by cognitive or visual information processing theory (e.g., Carroll, 1992), our approach to behavioral assessment is driven PRIMARILY by psychometric theory and our process of test selection and development requires that a task or sub-test show reliability and stability (Kennedy, Wilkes, Dunlap, & Kuntz, 1987) before attempting to describe the particular underlying dimension being indexed. This philosophy for test development can be thought of as a marginal utility model, in which addition and subtraction of tests to the battery occur in connection with value added PSYCHOMETRICALLY. In this case, reliability, factor richness, sensitivity, and predictive validity are the chief psychometric criteria along with the testing time required to obtain satisfactory statistical properties. The six tests selected for the battery are described in detail in Jones and Kennedy (1995). Brief descriptions are given below:

1) Saccadic Accuracy. A square C opening to the right or opening to the left is presented on the left side of the screen and then on the right side. Subjects have four seconds to report whether the opening of the C on the left and right sides of the screen are in the same or different direction.

2) Simultaneity. With the subject staring at a fixation point in the middle of the screen, two open boxes spaced 33mm apart are alternately flashed on the screen for 60 msec. Subjects report whether the left or the right box appeared first.

3) Stroboscopic Motion. Braddick & Adlard (1978). An array of stimuli (boxes) is alternately cycled. Frame one consists of three horizontal elements of boxes with equal center-to-center distances. Frame two has identical elements shifted to the right by a distance equal to the center-to-center separation between stimuli. Subjects report whether they perceived "element" motion or "group" motion. If on any trial subjects report "element" motion ISI is increased; if subjects report "group" motion, ISI is decreased.

4) Phi Phenomenon. To elicit perceptions of apparent motion, opaque squares 33mm apart on the screen of the microcomputer are presented so that when viewed at .4m, objects would be about two degrees to the left and right of fixation. Subjects use a set of response keys to adjust ISI to the point at which objects appear to move back and forth.

5) Critical Flicker Frequency. Subjects report the luminance point at which flicker is perceived on the screen. A small square is presented in the middle of the display. Subjects press the <UP> or <DOWN> arrow key until a no-flicker state is observed. VGA electron guns are manipulated based on key presses to decrease or increase intensity of the square. When the subject is satisfied, the <ENTER> key is pressed to indicate the choice.

6) Masking. Two vertical lines .75 degrees in length and .05 degrees wide are presented. A horizontal line .05 degrees in length extends from the midpoint of either the left or right vertical line. After a brief period, the lines are replaced by a complex pattern of dots (the mask). The screen is blanked and the subject is instructed to press either the left or right arrow keys, depending upon whether the horizontal line was on the left or right vertical line. A brief tone signals the start of each trial.
Participants. A sample of 58 Navy and Marine Corps active duty student aviators were tested at the Naval Aerospace Medical Research Laboratory, Pensacola, Florida for the first study. A sample of 45 undergraduate psychology students from the University of Nevada, Las Vegas received extra credit for their participation in the second study.

Results
Baseline trials (3 and 4) were averaged prior to analysis. Factor analyses were performed separately on the two groups. Factors were extracted using Principal Axis Factors, iterated until communalities stabilized, and rotated by the Normalized Varimax Method. Both analyses produced two factors, generally congruent across the two groups. We have not labeled either of the two factors. The first and largest has major loadings on Phi and Strobe, with a secondary loading (in study 2 only) shown by Critical Flicker Frequency (CFF). The second factor links (in both studies) Saccadic Accuracy and Simultaneity, with CFF present on Factor II in study 1, but not in study 2. Masking fails to load on either factor in study 1, but has a moderate secondary loading on Factor II in study 2.

While the factors appear to be consistent and reasonably well determined, we consider them tentative until we have an opportunity to replicate the analyses and, relatedly, to include more temporal tests (LOOM, Dynamic Visual Acuity, etc.) in the analyses (Kennedy, Compton, Drexler, Smith & Smither, 1999; Kennedy & Compton, 2001). Current findings do suggest, however, that the dimensions underlying the battery are somewhat fewer than the number of tests, and replication of structure across the two studies indicates that the dimensions not yet identified are probably real. The factor structure of the variables in both studies is shown in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Task</th>
<th>Factor I</th>
<th>Factor II</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccadic Accuracy</td>
<td>0.55</td>
<td>0.31</td>
<td></td>
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<tr>
<td>Phi Phenomenon</td>
<td>0.77</td>
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<td>Simultaneity</td>
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<tr>
<td>Critical Flicker Frequency</td>
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<tr>
<td>Stroboscopic Motion</td>
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<td>0.93</td>
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<tr>
<td>Masking</td>
<td></td>
<td></td>
<td>0.02</td>
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<tr>
<td><strong>Eigenvalue</strong></td>
<td><strong>1.55</strong></td>
<td><strong>0.63</strong></td>
<td></td>
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</table>

N = 58; Percent of Variance Extracted = 36.3%; Loadings below 0.20 are omitted

Table 1. Two-factor solution for study 1

Discussion
The main goal of our research was to develop a battery of computer-based tests that would characterize an individual’s motion perception capabilities. A secondary goal was to determine how these abilities are affected by important variables such as alcohol, aging, and sleep loss. In our extensive assessment of the battery over the last ten years we have found evidence that these tests are reasonably sensitive moderate levels (.05-.07) of BAC levels (Jones, Chronister, et al. 1998;
Jones, Kennedy, Rugotzke, et al. 1998; Kennedy, Ritter, et al. 1996). We have also been able to link performance decrements on these tests to aging (Kennedy, Jentsch, et al. 2001; Kennedy, Ritter, et al. 1996). Relatedly, Dawson and Reid (1997) made an intriguing point in a cross-over study in which they subjected the same participants to alcohol and to fatigue caused by sleep loss and then measured their cognitive psychomotor performance and their eye-hand coordination at half-hourly intervals. Results indicated that “… relatively moderate levels of fatigue impaired performance to an extent equivalent to or greater than is currently acceptable for alcohol intoxication.” More specifically, the researchers discovered that after 17 hours of sustained wakefulness, cognitive performance decreased to a level equivalent to performance impairments observed at a BAC of 0.05%. In a similar paradigm, Kennedy and Jones (unpublished) have replicated their “dose equivalency” results for the temporal factors battery where comparable levels of alcohol and sleep loss can be reported.

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<th>Task</th>
<th>Factor I</th>
<th>Factor II</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccadic Accuracy</td>
<td>0.63</td>
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<tr>
<td>Phi Phenomenon</td>
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<td>Simultaneity</td>
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<td>Critical Flicker</td>
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<tr>
<td>Frequency</td>
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<tr>
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<td><strong>1.05</strong></td>
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N = 45; Percent of Variance Extracted = 35%; Loadings below 0.20 are omitted

Table 2. Two-factor solution for study 2

In effect, we now have a psychometrically sound battery for the assessment of temporal motion perception. We are also able to link performance on this battery to the adverse effects of alcohol, aging and fatigue; all variables that have consistently been linked to higher risk of auto accidents. Furthermore, given that driving requires transient visual capabilities and that the disruption of visual performance due to alcohol ingestion and other stressors is greater for tests involving transient visual capabilities than for tests of static visual performance, we believe that our battery will be extremely useful as we fine tune the predictive power of the sub-tests and investigate the battery’s ability to predict performance on the road.

**References**


