2013

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EFFECTS OF EVENT RATE ON CEREBRAL BLOOD FLOW VELOCITY DURING VIGILANCE PERFORMANCE

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Transcranial Doppler sonography (TCD) was used to assess the effects of event rate on cerebral blood flow velocity (CBFV). Fast (30 events/minute) and slow (5 events/minute) event rates were employed in a 40-minute vigilance task that simulated the control of remotely piloted aircraft. As is typical in vigilance tasks, signal detection declined over time but there was no performance difference in conjunction with the two event rate conditions. Nevertheless, CBFV was greater in the fast than in the slow event rate condition and declined significantly with time on task. These outcomes support previous findings of a close tie between CBFV and the vigilance decrement and suggest the possibility that in regard to event rate, CBFV is a more sensitive index of task demand than performance itself.

Vigilance, or sustained attention tasks require observers to maintain their focus of attention and detect the appearance of critical signals over prolonged periods of time. This aspect of performance is of interest to the Air Force because of the critical role that operator vigilance plays in enemy surveillance, cockpit monitoring, air-traffic control, and airport and border security (Warm, Parasuraman, & Matthews, 2008). A key finding in vigilance performance is that sustained attention is fragile, it wanes over time. This is reflected in what is known as the vigilance decrement, a decline in the speed and accuracy of signal detections with time on task (Warm et al., 2008). The resource model proposed by Davies and Parasuraman (1982) is a major conceptual framework for understanding the decrement. According to that view, the need to make continuous signal/noise discriminations depletes information-processing assets or reservoirs of energy that cannot be replenished in the time available. Hence, the temporal decline in performance efficiency. Support for the resource model comes from findings that vigilance tasks impose a high level of perceived mental workload on observers which increases with increments in psychophysical demand, that vigilance tasks promote high levels of stress, and that the decrement is correlated with observers' feelings of mental exhaustion (Warm et al., 2008; Warm, Finomore, Vidulich, & Funke, in press).

It is important to note that the resource model has been criticized on the grounds that resources are not measured directly. Instead, they are inferred from performance and therefore, explaining performance changes in terms of resource loss represents circular reasoning (Navon, 1984). Recent research has sought to counter this criticism by assessing resources independently of performance using a non-invasive neuroimaging procedure known as Transcranial Doppler sonography (TCD). The TCD procedure employs ultrasound signals to monitor cerebral blood flow velocity (CBFV) or hemovelocity in the middle cerebral arteries which carry about 80% of the blood within each hemisphere (Toole, 1984). When a particular area of the brain becomes active, as in the performance of mental tasks, by-products of this activity, such as carbon dioxide, increase which lead to an increase in CBFV to the region to remove the waste product (Aaslid, 1986). Consequently, TCD offers the possibility of measuring changes in metabolic activity during task performance and it has been used to do that in a wide variety of cognitive, perceptual, and motor tasks (Tripp & Warm, 2007). As reviewed by Warm and his associates (Shaw, Finomore, Warm, & Matthews, 2011; Warm et al., 2008), studies with regard to vigilance have shown that the level of CBFV varies directly with task demand as determined by variations in several task parameters (e.g., memory load, stimulus uncertainty, signal presence/absence), that the vigilance decrement is accompanied by a temporal decline in CBFV, and that these effects occur primarily in the right hemisphere, indicating a right hemispheric system in the functional control of vigilance. Of critical importance are the findings that the temporal decline in CBFV occurs with both visual and auditory tasks indicating that the effect is general in nature (Shaw et al., 2009) and that it only appears when observers are actively engaged in a vigilance task. Bloodflow velocity remains constant over time when participants observe the vigilance display in the absence of a work imperative, revealing CBFV changes to be task related (Warm et al., 2008). The present study was designed to extend the investigation of CBFV and vigilance by examining hemovelocity effects in the context of a critical psychophysical parameter in vigilance - the background event rate - that has not as yet been examined in regard to bloodflow velocity changes.

Vigilance tasks often employ dynamic displays in which the critical signals for detection are embedded within a matrix of recurring neutral background events. An example would be the need to detect the occasional appearance of a slightly longer line in a cascade of short lines. While the background events may be neutral in the sense that they do not require an overt response from the observer, they are not neutral in their effects on signal detection. The frequency of the background events or the background event rate is a key element in determining performance efficiency. The accuracy of signal detections varies inversely with event rate, the vigilance decrement tends to be more pronounced in the context of a fast as compared to a slow event rate, and the background event rate has been shown to be a moderating variable in regard to the effects of other factors such as signal amplitude and the demands of multi-tasking (Davies & Parasuraman, 1982; Warm et al., in press). Findings such as these have led to the view that event rate is probably the prepotent psychophysical factor in regard to vigilance performance (Parasuraman, Warm, & Dember, 1987).

From the framework of the resource model, the degrading effects of increments in event rate can be interpreted in terms of the greater consummation of information processing assets in a fast as compared to a slow event rate condition brought about by the higher frequency of signal/noise discriminations demanded in the fast event rate condition. Given the greater resource demand in a fast as compared to a slow event rate condition, it might be anticipated that the overall level of CBFV and the temporal decline in CBFV would be greater in the context of a fast than a slow event rate. Moreover, given the evidence pointing to a right-hemispheric system in the control of vigilance, it might also be anticipated that the CBFV effects associated with event rate would be lateralized to the right cerebral hemisphere. The present study was designed to test these possibilities.

Method

Participants

Twenty individuals from the Dayton, OH area (10 males and 10 females) served as observers for a single payment of $30. They ranged in age from 18 to 30 years old. All observers had normal or corrected-to-normal vision and were right handed, as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). The experiment was conducted under conditions approved by the WPAFB Institutional Review Board.

Experimental Design

This study employed a 2 (Event Rate) × 2 (Cerebral Hemisphere) × 4 (Periods of Watch) mixed-design. Ten observers were assigned at random to either a slow or fast event rate condition with the restriction that sex was equated within conditions. All observers participated in a 40-minute vigil divided into 4 continuous 10-minute periods of watch.

Vigilance Task

Observers assumed the role of controllers monitoring the flight paths of remotely piloted aircraft (RPA) on a 17-inch visual display terminal (VDT). The vigilance display, which was modeled after that used by Hitchcock et al. (2003), is shown in Figure 1. It consisted of a "city" signified by a solid red circle (10.5 mm in diameter; transluminance = 21.4 cd/m^2) surrounded by a thin white border (0.75 mm thick × 12 mm in diameter), three concentric white outer markers (0.75 mm thick, 28, 53, and 83 mm in diameter, respectively; transluminance = 79.9 cd/m^2), and two lines representing RPA flight paths (1 × 25 mm; transluminance = 30.6 cd/m^2). The displays were presented on a light gray background (transluminance = 29.5 cd/m^2). The Michaelson Contrast Ratio ([maximum luminance – minimum luminance / maximum luminance + minimum luminance]; Coren, Ward, & Enns, 1999) of the RPA flight paths to the background was 1.83% (light gray targets on a light gray background). Each aircraft approached from opposite headings, in either a NW to SE or SW to NE direction. Safe flight paths or neutral events were those in which the flight headings of two RPAs were slightly displaced to the left or right of the center of city so that they would pass each other without collision. Critical signals for detection were RPAs that were aligned on a collision path over the center of the city. Observers were instructed to press the spacebar on a computer keyboard in the presence of a critical signal and to make no response to non-critical signals. Neutral events and critical signals are displayed in the left and right of Figure 1, respectively.

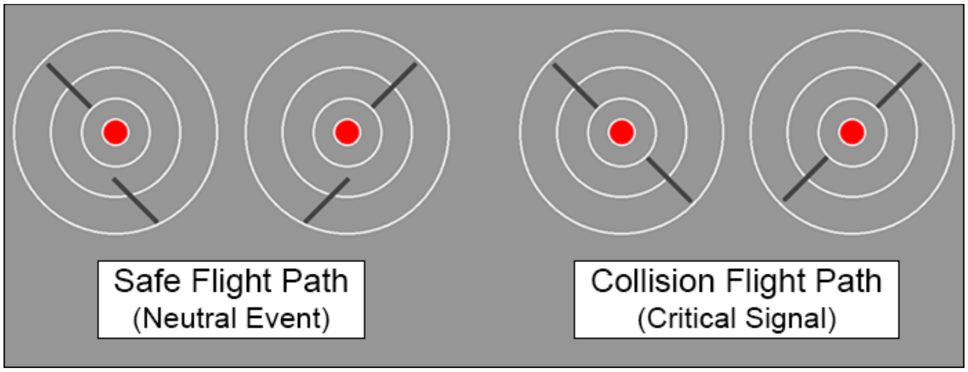

Figure 1. Examples of neutral and critical signals presented in the display. The contrast of the RPA flight paths to the background has been increased in the figure for clarity of presentation.

In the slow event rate condition the display was updated 5 times per minute while in the fast event rate condition it was updated 30 times per minute. In both conditions, the dwell time per stimulus event was 80 ms. Responses made within 1200 ms of the onset of a critical signal were considered as correct detections or "hits." All other responses were considered as errors of commission or "false alarms." Ten critical signals were presented per period in all conditions. Each experimental session was preceded by a 5-minute resting period during which CBFV was recorded. CBFV was assessed bilaterally using TCD. As recommend by Aaslid (1986), baseline scores for CBFV were determined by averaging the last 60 seconds of the resting period. Following the resting period, observers in all conditions received a 5-minute practice session. During practice, feedback was provided by a computer generated female voice, which indicated correct detections, false alarms, and misses. Observers were required to detect at least 5 out of 10 critical signals during this time in order to be included in the study. Audio feedback was removed during the main portion of the experimental session. Observers surrendered all timepieces and electronic devices upon reporting for the experiment. Stimulus presentations and vigilance response recording in all conditions were controlled by a Dell PC running Windows XP.

Experimentation was conducted in a 2.48 × 2.45 × 2.16 m windowless sound attenuated booth. The VDT was mounted on a table 70 cm directly in front of the seated observer (visual angles for the VDT and the stimulus display were 32.87° and 6.79°, respectively) Ambient illumination in the testing booth was 2.5 cd/m^2, provided by two 17-watt fluorescent bulbs, occluded on all sides and positioned above and adjacent to the seated observer to minimize glare on the VDT.

Hemovelocity Measurement

A Nicolet Companion III TCD machine was used to index changes in CBFV. CBFV was measured bilaterally using two 2-mHz ultrasound transducers. Measurements were taken from the left and right medial cerebral arteries (MCAs).The transducers were secured in a plastic bracket which was attached to an adjustable plastic headband and secured to the observers head, located dorsal and immediately proximal to the zygomatic arch along the temporal bone. Aquasonic 100-brand gel was placed between the transducer and the observer's skin to amplify the ultrasound signal. In the current study, the MCA was generally monitored at depths of 50-55 mm. CBFV measures were recorded by the TCD unit at approximately 1 Hz.

Results

Performance Efficiency

Mean numbers of correct detections and false alarms in the two event rate conditions are plotted as a function of periods of watch in Figures 2 and 3, respectively. It is evident in both figures that the scores for the event rate conditions were similar to each other and that they declined over time. Separate 2 (Event Rate) × 4 (Periods) split-plot analyses of variance (ANOVAs) of the correct detection and false alarm data revealed that in both cases the main effect for periods of watch was statistically significant, $F_{Correct\ Detections}$ (2.69, 48.44) = 5.91, $p < .01$, $\eta^2 = .25$; $F_{False\ Alarms}$ (2.81, 50.62) = 4.08, $p < .05$, $\eta^2 = .19$, while the main effect for event rate and the event rate × periods interaction were not significant, $p > .05$ in each analysis. In these and the subsequent ANOVA of the bloodflow data, the Box correction was employed when needed to adjust for violations of the sphericity assumption (Field, 2009).

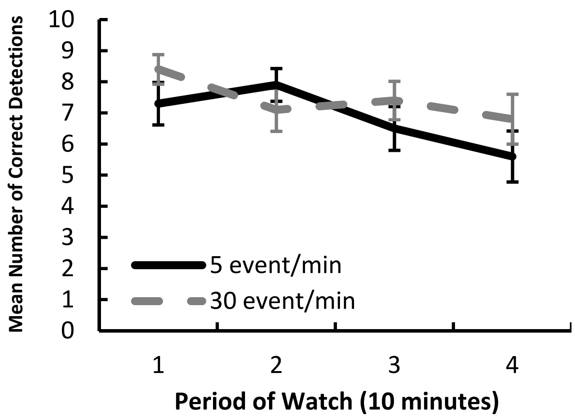

Figure 2. Mean number of correct detections for the slow and fast event rate conditions as a function of periods of watch. Error bars are standard errors.

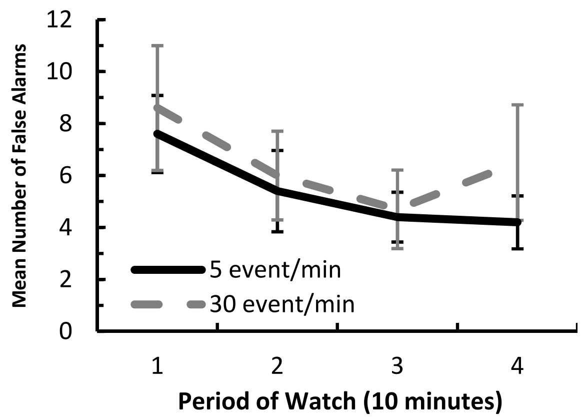

Figure 3. Mean number of false alarms for the slow and fast event rate conditions as a function of periods of watch. Error bars are standard errors.

Hemodynamics

CBFV was measured within the left and right hemispheres for all combinations of event rate and periods of watch. In order to control for individual variability, CBFV was expressed as a proportion of the last 60 seconds of the 5-minute resting baseline (Aaslid, 1986). Mean CBFV scores for the two event rate conditions are plotted as a function of periods in Figure 4. Data for the left and right hemispheres are presented separately in each panel. It is evident in the figure that CBFV was greater for the fast than for the slow event rate in both cerebral hemispheres and that in both hemispheres, CBFV declined over time in the two event rate conditions. These impressions were supported by a 2 (Event Rate) × 2 (Hemisphere) × 4 (Periods of Watch) mixed-ANOVA which revealed significant main effects for event rate, F (1, 18) = 4.82, $p < .05$, $\eta^2 = .21$, and periods of watch, F (2.12, 38.18) = 10.64, $p < .001$, $\eta^2 = .37$. The main effect of hemisphere and all interactions in the analysis were not significant, $p > .05$ in each case.

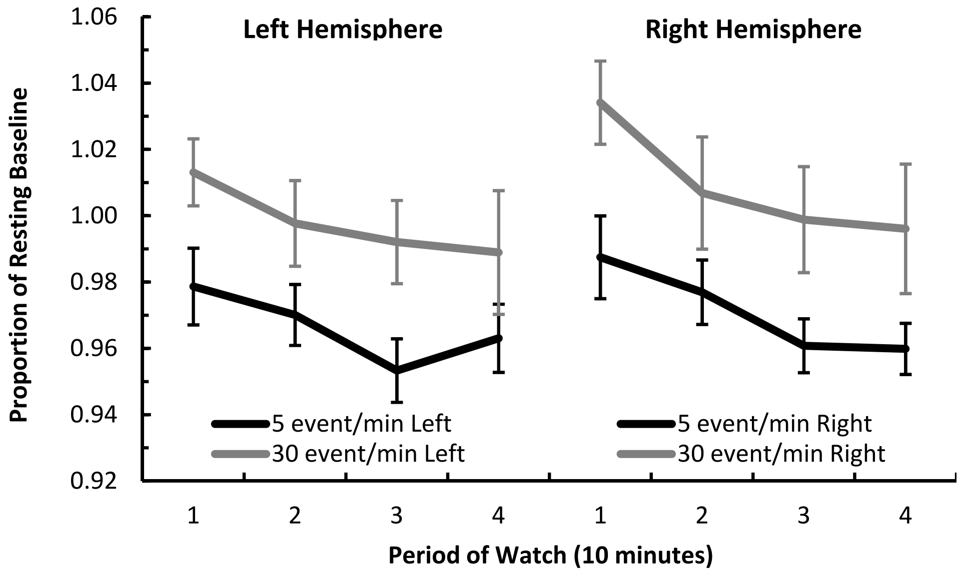

Figure 4. Hemovelocity scores for the two event rate conditions as a function of periods of watch. Data are plotted separately for each cerebral hemisphere. Error bars are standard errors.

Discussion

The present study tested several possibilities regarding the effects of background event rate on CBFV in a vigilance task. Specifically, it was anticipated that the overall level of CBFV would be greater in the context of a fast as compared to a slow event rate, that the decline in CBFV over time would be positively related to event rate, and that these effects would be lateralized to the right cerebral hemisphere. As expected, CBFV was greater with a fast event rate of 30 events/minute than with a slow rate of 5 events/minute. It is noteworthy that in addition to the rate of repetition of the background events in which critical signals occur in a vigilance task, the background events can also be varied in terms of whether they occur in a temporally regular or a temporally irregular manner. A recent study by Shaw et al. (2011) has found that CBFV is greater when the background events occur in an asynchronous or irregular than a synchronous or regular format. Taken together, the results of the present study and the experiment by Shaw and his associates demonstrate the importance of the background events in which critical signals are embedded on hemodynamics in vigilance performance.

Although the expectation regarding the relation between the overall level of CBFV and event rate was confirmed, the expectations regarding the temporal decline in CBFV and event rate and the lateralization of the CBFV effects were not supported by the data. Consistent with several earlier investigations (see Warm et al., 2008), CBFV declined significantly over time in this study, but the decline was independent of event rate and the CBFV effects associated with event rate and time on task were similar in both the right and left cerebral hemispheres. The absence of hemispheric effects is contrary to several earlier CBFV studies showing a right hemispheric system in the functional control of vigilance performance (Shaw et al., 2011; Warm et al., 2008). It is important to note, however, that the dominance of a right hemispheric control system in vigilance has been challenged by several recent studies showing bilateral activation in vigilance tasks (Helton et al., 2010; Schultz, Matthews, Warm, & Washburn, 2009; Shaw et al., 2011). Thus, while an overall right hemispheric system might be involved in the control of vigilance in some cases, in others, such as the present study, a cooperative interaction model (cf., Shaw et al., 2011) may best describe the role of cerebral functioning in the management of sustained attention. Future research is needed to discover the factors that determine brain symmetry and asymmetry in the maintenance of sustained attention under different experimental conditions.

A key feature of the relation between CBFV and vigilance is the parallel between CBFV and performance efficiency. That parallel was evident in the present study with regard to the temporal decrement in CBFV and the decline in the frequency of signals detection with time on watch. However, the CBFV/performance correspondence was not evident in regard to the effects of event rate. While CBFV was higher in the context of the fast as compared to the slow event rate, the two event rate conditions did not have differential effects upon the frequency of signal detection. At present, the reason for the lack of a performance difference between the two event rate conditions is not clear. However, to the extent that CBFV is an index of the utilization of information-processing resources, it would appear that in regard to event rate, it is a more sensitive index of task demand than performance efficiency. Even when performance differences were absent, the CBFV measure indicated that resource utilization was greater in the context of the fast as compared to the slow event rate.

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