Event expectancy and inattentional blindness in advanced helmet-mounted display symbology

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Abstract

Helmet-mounted displays (HMD) have the potential to significantly increase helicopter flight safety by superimposing synthetic information in the forward field of view. Particularly during poor visibility, decreasing workload and enhancing situation awareness are two key factors. However, previous findings mainly within the scope of head-up displays in fixed-wing aviation have shown that superimposed displays also pose a risk of impairing the detection of unexpected events. The present paper will investigate this topic in the context of new HMD symbology concepts for rotary-wing aircraft. The designs were tested in a simulator study with 18 civil and military pilots. Primarily, attention distribution in terms of concurrent task performance was investigated. In addition, two unexpected events occurred, a warning on the display and a traffic incursion in the outside scene. Results revealed a later response to the warning on the HMD, if it was presented truly unexpected and in poor visibility. Moreover, a trend towards an HMD detection cost for the traffic incursion was observed.

Introduction

In recent years helmet-mounted displays became increasingly important for rotary-wing aircraft. They provide pilots with relevant flight information by presenting symbology in the forward field-of-view. Therefore head-down time and scanning costs between instruments and outside environment can be reduced. As a result, divided attention tasks are facilitated by enabling a parallel monitoring of the two domains. This advantage is essential, since maintaining constant visual contact with the environment is time-critical especially in low altitude flight and poor visibility conditions. Nevertheless, an appropriate symbology design is crucial to enhance situation awareness and reduce workload and spatial disorientation. Moreover, it has been found that event detection performance with superimposed displays is largely dependent on the expectancy of the events. Expected events are usually classified as those who are naturally expected during flight, occur frequently or have specifically been briefed. In contrast, unexpected events refer to those who occur truly surprising, rarely, are usually not anticipated or briefed. Findings in literature indicate that head-up displays usually facilitate the detection of expected events in the environment or on the display. However, costs have often been observed in the

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detection of unexpected events, especially if they occur in the outside scene and are not very salient (Fadden, Ververs, & Wickens, 1998; Wickens & Long, 1994, 1995). For instance it was found that runway incursions during approach are detected later with a head-up display, a result that was also observed with HMDs by Lorenz, Többen, and Schmerwitz (2005). The finding can be attributed to both a cost of clutter, as well as attentional tunneling. The former hinders event detection by presenting too much information in the forward field of view and by obscuring objects with the symbology. The latter refers to an inadequately long allocation of attention to the symbology that leads to neglecting relevant events on other channels as well as failing to perform other tasks (Wickens & Alexander, 2009). These findings can further be related to the concept of inattentional blindness (Mack & Rock, 1998) since it is described as a "failure to see highly visible objects we may be looking at directly when our attention is elsewhere" (Mack, 2003, p. 180). As a result, simply superimposing symbology to assume parallel processing of information within a specific area or spotlight of attention, as adapted from space-based attention theories (Eriksen & Eriksen, 1974) has proven not to be efficient. The topic is discussed elaborately in the context of head-up displays in Wickens and Long (1995). It has rather become evident that selective attention is in fact driven by bottom-up processes such as saliency and effort, as well as top-down processes such as expectancy and value, constituting the basic components of the SEEV-model (Wickens, Helleberg, Goh, Xu, & Horrey, 2001; Wickens & McCarley, 2007). In general, Wickens and Alexander (2009) point out that the unexpected event detection cost should not lead to the overall conclusion to classify superimposed displays as being generally problematic. Moreover using conformal symbology was found to mitigate this problem. It refers to symbology that is somewhat linked with the far domain by being spatially aligned with actual or virtual objects in the environment, such as conformal horizon lines, runways or obstacles. Nevertheless it has to be noted that the previous literature very strongly focuses on head-up displays in the fixed-wing domain, or monocular HMDs with a rather small field of view. The present paper, however, investigates the use of conformal symbology in modern, binocular HMDs and focuses on low altitude and poor visibility helicopter operations. Therefore new symbology concepts for en route and landing assistance featuring conformal obstacle and route presentations were tested in a real-time simulation. Test subjects were instructed to monitor for attitude changes on the display and perform a search and identification task in the outside scene. Furthermore two unexpected events were presented. The paper subsequently focuses on the unexpected event detection results. Findings regarding the main task performance are described in Knabl, Schmerwitz, Doehler, Peinecke, and Vollrath (2014).

Method

Participants

Eighteen pilots with an average age of 45 years (SD = 7) participated in the study. Nine were military pilots from the German Armed Forces and nine were civil pilots from the German Federal Police Force and the German (DRF) and Swiss (REGA) air rescue providers. Their average flight experience was 4401 (SD = 3867) flight hours in total and 1167 (SD = 758) on the presently operated helicopter type. 17 pilots were instrument rated. Six had experience with an HMD in the simulator, four had additional experience in real flight, and eight had never flown with an HMD before. Their HMD experience averaged 178 (SD = 366) flight hours. The aircraft types most frequently operated were the EC 135, NH 90 and AS 332.

Apparatus

Helmet-mounted display
The HMD used was a JEDEYE™ helmet system by Elbit Systems Ltd. (figure 1). It features a wide field of view (80° x 40°) and a very high resolution (2 x 1920 x 1200 px). Table 1 provides the most significant technical specifications.

Table 1. Technical specifications of the JEDEYE™ helmet system.

Resolution	2x1920x1200 pixel @ 60 Hz
Field-of-view	binocular, 2x80°x40°, stereo capable
Head tracker	magnetic, 400 Hz, precision 0.25°
Weight	approx. 2.3 kg incl. helmet
Interface	RS-170, SDI, DVI-D, HDMI
Colour space	monochrome green

Simulator
The fixed-base simulator GECO (generic cockpit simulator, figure 1) provided a collimated projection with a resolution of 3 x 2560 x 1440 pixel spreading 180° x 40°. The cockpit shell was a model of an Airbus A320, but furnished with the HMI layout of an A350. In order to allow helicopter experiments the simulator was equipped with a cyclic and collective on the right seat. Both inputs allowed active feedback. The regular yaw control was modified to have low resistance and no resilience. As flight model an EC-135 was used with the software simulation tool X-Plane10. The realism of the model was rather low but allowed easy handling for the test subjects. The cockpit shell did not provide enough forward slant view due to the high glare shield. Therefore the simulated horizon was tilted 5° upwards. None of the participants commented on having been irritated by this.

Experimental design

Each pilot conducted twelve scenarios, six with the use of the HMD and the same six with the head-down baseline condition. The visual condition as well as the display and scenario order was permuted. Half of the participants completed all scenarios with the HMD followed by the baseline scenarios and vice versa. Within each display condition three scenarios started with average visibility changing to poor half way through the run and vice versa.

Figure 1. Generic Cockpit Simulator (GECO) and JEDEYE^{TM} helmet system.

Procedure

The trials took place from March till May 2014 at the DLR Institute of Flight Guidance. Each pilot spent a full eight hour day at the institute. The morning session consisted of an introduction, briefing, familiarization and training, the afternoon session of testing and de-briefing. Within the training phase the participants were given time to become accustomed to the aircraft and HMD symbology. Moreover the primary tasks were trained. All test subjects signed a letter of consent and filled out a biographical questionnaire, containing questions about age, flight experience, usage of HMD, as well as experience with brownout and spatial disorientation. The actual test phase was split into two blocks, each taking approximately 80 minutes to complete, and separated by a 15 minute break. A block consisted of six scenarios with one display set. Pilots wore the HMD with the visor folded down also in the baseline scenarios to ensure equal brightness and contrast. The de-briefing collected various subjective aspects using tailor-made questionnaires with regard to helmet use and symbology design.

Symbology

Both display types (head-down and head-up) presented almost identical situation and navigation information. The head-down variant was designed according to the fielded instrumentation of DLR's EC135 helicopter ACT/FHS and was split into two screens, the primary flight display (PFD) (figure 2, top left) and the navigation display (ND) (figure 2, bottom left). In the simulator they were located directly in front of the pilot and shared a 15.4'' TFT with 1440x900 pixels. The PFD primarily delivered information on speeds, heading, heights and attitude/horizon. To maintain high transparency within the helmet display (low clutter) the representation of information was greatly simplified (figure 2, top right). Additionally the head-up symbology was presented in monochrome green whereas the head-down symbology was presented in colour. The type of "glass cockpit"-PFD was well known to almost all pilots. The significant difference of the HMD symbol set was the combined presentation of PFD and ND into an egocentric perspective display (figure 2, bottom right). The predetermined route was visualized by route points consisting of virtual conformal, terrain-based arrows, and waypoints presented as poles. Furthermore, conformal obstacles (power lines, windmills and towers) were depicted, whereas the head-down symbology did not feature obstacle highlighting. Finally, the ND delivered route and waypoint information in a heading-up mode. Distance scaling was deactivated to allow for identical presentation to all participants.

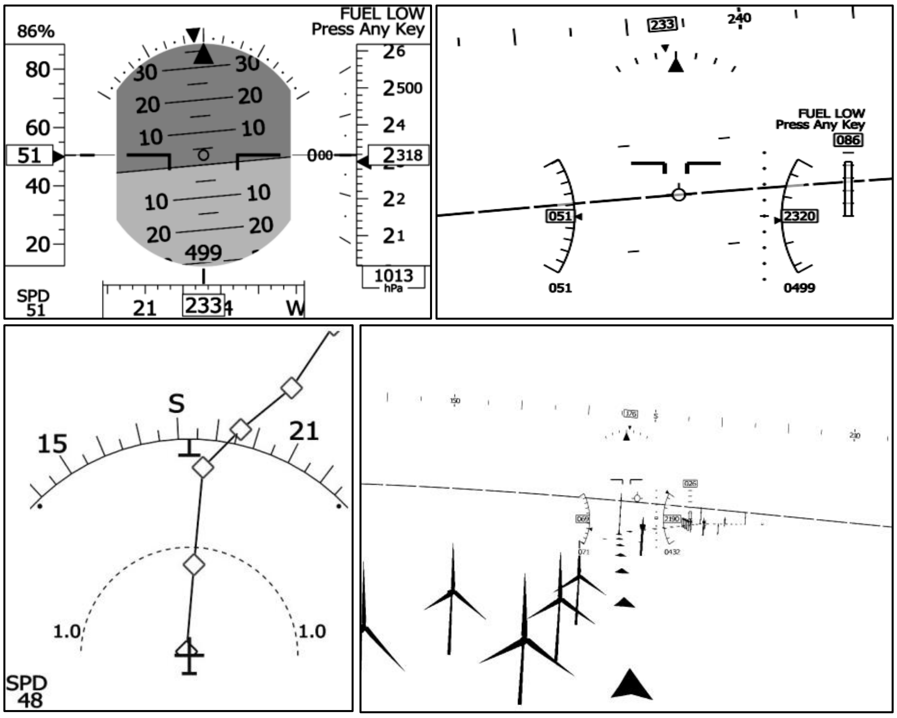

Figure 2. Head-down displays (left) and helmet-mounted display (right). Primary flight displays (top) and navigation displays (bottom).

Scenario design

Scenarios were started from a freeze position in the air. Each scenario consisted of an en route and an approach/landing phase and took approximately 10-12 minutes to complete. Two visibility conditions occurred and visibility always changed after half of the en route phase. Poor visibility provided a visual range of approximately 800 m, and average visibility provided a range of 1200 m.

Expected events

During the en route segment pilots were instructed to perform two different tasks, a monitoring task on the display, and a search and identification task in the outside scene. Within the monitoring task they were briefed to monitor for heading, speed and altitude changes and adjust the parameters timely and accordingly. Twelve changes occurred in each scenario. In the far domain task they were instructed to search for small fuel trucks positioned in the terrain. Trucks differed in their colour: green trucks were labelled as friend targets, red as foe targets, and grey as neutral targets. Participants had to detect the trucks, determine the correct colour and report it by pushing a corresponding button on the centre stick. The particulars of the main tasks are presented in detail in Knabl et al. (2014).

Unexpected events

Additionally two unexpected events occurred, one on the display and one in the outside scene. Pilots were not briefed about the appearance of these events. Both appeared twice, once with the HMD, and once with the baseline condition. Thus each event was only once truly unexpected. For half of the participants the events first occurred with the HMD and afterwards with the baseline condition, for the other half it was the opposite. Furthermore, for one half they appeared in poor, for the other in average visibility.

The display event consisted of a warning stating “fuel low press any key”. The warning appeared above the altitude tape, blinked with 2 Hz for four seconds and then remained steady until any button was pushed (figure 2, top). The far domain event consisted of an intruder helicopter hovering in the flight route (figure 3). Pilots were required to detect the aircraft and perform an adequate collision avoidance manoeuvre. The helicopter was only visible in the outside scene since no traffic was presented on any display.

Figure 3. Far domain event: intruder helicopter hovering in flight route

Data analysis

Data were analysed with SPSS Statistics 20. An alpha level of .05 was adopted for significance. Statistical analysis was conducted using repeated measures analysis of variance (ANOVAs) and t-tests. Data are further presented as mean (M) and standard deviation (SD).

Results

Helicopter event detection

Firstly, the frequency of lateral and vertical manoeuvres was determined to assess the overall quality of collision avoidance. Lateral manoeuvres, especially right turns, were regarded as most adequate. Based on pilot comments, a right turn would be the typically used manoeuvre (in countries with right-hand traffic), although it is not specifically stated as a rule. Therefore left turns were considered as adequate as well, given that the pilot recognised the helicopter being in a hover and not in a forward movement. Vertical manoeuvres however were regarded as less appropriate, since the helicopter would either receive or cause turbulence due to the rotor downwash. Descriptive results indicated that the helicopter was predominantly avoided by a lateral manoeuvre and right turns were also most frequently selected. A vertical manoeuvre was selected only twice with the PFD condition, however six times with the HMD. In one PFD scenario the pilot was so far off-track that no reaction was required. Finally, one pilot in the HMD condition did not react at all and commented that he would have probably collided with the helicopter, if he had not already been at a too high altitude. Apart from that near-miss, no collision occurred.

Table 2. Descriptive results of collision avoidance manoeuvre type

Collision avoidance manoeuvre type	frequency		minimal distance achieved (m)	
	HMD	PFD	HMD	PFD
Right turn (behind helicopter)	6	9	33.5	24.6
Left turn (in front of helicopter)	5	6	32.9	25.7
Descent (below helicopter)	2	2	13.3	13.4
Climb (above helicopter)	4	-	16.3	-
No reaction (off track)	-	1	-	-
No reaction (not detected)	1	-	-	-

Secondly, based on the visual inspection of the manoeuvre and analysis of the control inputs, the start of the avoidance manoeuvre was determined and the distance to the helicopter was calculated. However, it has to be noted that the exact starting point was not always apparent. Therefore statistical analysis was carried out only for 12 pilots. Due to the rather small sample size visibility and order of appearance were not accounted for. A one-way repeated measures ANOVA revealed no significant main effect of display condition, $F(1, 11) = 1.41$, $p = .260$, $\eta^2_p = .11$. Thus the distance to the helicopter at start of avoidance did not statistically differ between the HMD ($M = 366.5$, $SA = 144.7$) and the baseline ($M = 444.3$, $SA = 180.8$).

Warning detection

Reaction time from warning appearance to response was calculated as a function of display type (HMD/baseline), visibility condition (poor/average) and order of appearance (HMD or baseline first). A three-way split-plot ANOVA was calculated with the between subject factors visibility and order, and the within subject factor display. No significant main effects were obtained. However results revealed a significant interaction of display x order, $F(1, 12) = 7.0$, $p = .021$, $\eta^2p = .369$. Post-hoc t-tests for independent samples were calculated and revealed a significant order effect only for the HMD, $t(15) = 2.6$, $p = .020$, but not for the baseline, $t(15) = -1.2$, p = .248. Hence, when the warning appeared on the PFD, reaction time did not differ as a function of order, thus whether it occurred for the first (M = 3.2, SA = 1.0) or for the second time (M = 2.7, SA = 0.9). However, it was found that when the warning was presented on the HMD, pilots responded significantly later if it was truly unexpected (first: M = 4.5, SA = 1.6; second: M = 2.6, SA = 0.9). Moreover, the second order interaction (display x visibility x time) was also found to be significant, $F(1, 12) = 11.5$, $p = .005$, $\eta^2p = .489$. As illustrated in figure 4, the finding strongly indicated that the HMD reaction cost to the truly unexpected warning was only apparent in poor (M = 5.4, SD = 0.8) but not in average visibility (M = 3.0, SD = 1.3).

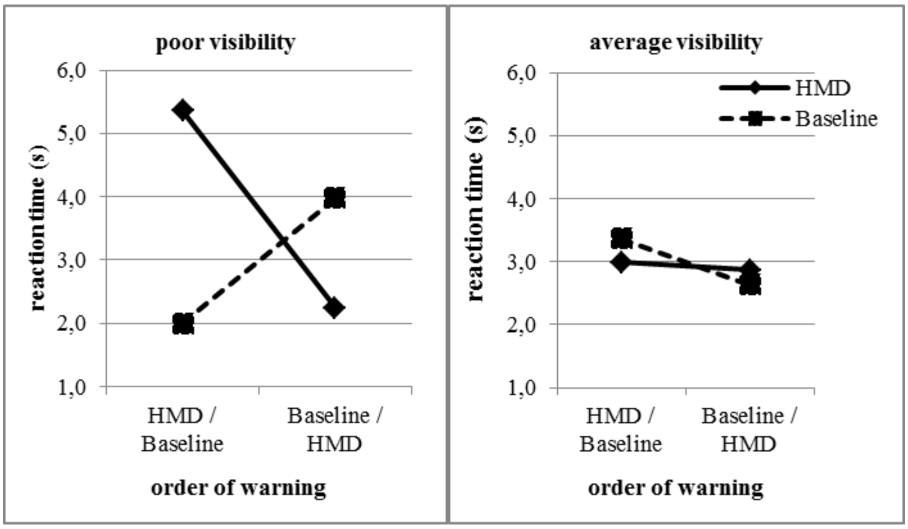

Figure 4. Reaction time (s) to warning as a function of display type, visibility and order

Discussion

With regard to the fuel low warning on the display, results revealed a longer reaction time with the HMD if the warning is truly unexpected. Interestingly the cost is only apparent in poor visibility, but not in average. It is assumed that in poor visibility pilots directed more attention to the far domain in order to avoid obstacles and search for targets, therefore the warning was responded to later. In contrast, the search task was less time-critical during average visibility conditions, enabling a more successful division of attention between the two domains and therefore a faster detection of the warning. However, it has to be assumed that attention was also more focused on the outside scene during the poor visibility PFD condition, although the detection cost is not apparent here. One possible reason for this is that the warning on the PFD - while focusing outwards - was presented in the peripheral visual field, which contains a large number of rods and is associated with a higher sensitivity compared to the fovea (Goldstein, 2013). Moreover the detection drawback was only obtained for the truly unexpected warning and disappeared with the second presentation. Thus saliency alone did not favour rapid detection, but expectancy did;

a finding which is in accordance with the SEEV model. Selective attention could therefore be directed quickly to the warning on the HMD, when it was presented for the second time. Further investigations should also raise the question whether expectancy is dependent on the location of the warning. Hence, is reaction time only reduced when the second warning appears at exactly the same position, or are test subjects also more susceptible to unexpected display events presented at a different display location?

With regard to the helicopter event, the descriptive results indicate that predominantly the most appropriate, lateral manoeuvre was chosen. However, vertical manoeuvres were selected more frequently with the HMD (six times) than with the baseline (twice). It has to be noted that no statistical analysis of the frequencies was performed due to the very small group size. No significant differences were obtained for the distance-based evaluation, indicating that pilots did not start their avoidance manoeuvre later with the HMD. Nevertheless, the results in general indicate a very slight but consistent tendency towards an HMD drawback that is supported by the following considerations. First, the higher frequency of vertical manoeuvres, second, the indication that descriptively pilots started the avoidance manoeuvres later. Third, at least one pilot specifically commented on indeed detecting the helicopter, however not having had enough time and cognitive resources left to consider a proper avoidance plan, which again might somewhat explain the higher frequency of vertical manoeuvres. Finally, the fact that one pilot did not detect it at all is consistent with findings from head-up display literature and is attributed to both the effect of clutter and attention fixation.

To sum up, the present paper provides evidence that, under certain conditions, HMD pose a risk of inducing event detection costs and that these hold true for both, events on the display and in the far domain. The findings are therefore consistent with previous results obtained from head-up display experiments. To mitigate these costs, technology-based solutions as well as human-centred solutions should be accounted for. With regard to technology, the implementation of enhanced vision based on real-time sensor data is a key factor. Highlighting or cueing objects such as traffic or obstacles on the HMD provide the possibility to specifically direct attention to these hazards. In addition, it is of interest whether detection performance can be improved by proper training, which would address the vulnerability to inattentional blindness and attentional capture and would create awareness of the susceptibility to these effects. Finally, for dual pilot operations, research should focus on crew procedures, task sharing and management as well as team situation awareness as well.

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References

Eriksen, C.W., & Eriksen, B.A. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143-149.

Fadden, S., Ververs, P.M., & Wickens, C.D. (1998). Costs and benefits of head-up display use: A meta-analytic approach. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 42,* 16-20.

Goldstein, E. B. (2013). Sensation and Perception, Cengage Learning.

Knabl, P., Schmerwitz, S., Doehler, H.-U., Peinecke, N., & Vollrath, M. (2014). *Attentional issues with helmet-mounted displays in poor visibility helicopter flight*. Paper presented at the 31st EAAP Conference, Valetta, Malta.

Lorenz, B., Többen, H., & Schmerwitz, S. (2005). Human performance evaluation of a pathway HMD. *Proceedings SPIE 5802, Enhanced and Synthetic Vision*, 166-176.

Mack, A. (2003). Inattentional Blindness: Looking Without Seeing. *Current Directions in Psychological Science*, *12*, 180-184.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA, US: The MIT Press.

Wickens, C.D., & Alexander, A.L. (2009). Attentional Tunneling and Task Management in Synthetic Vision Displays. *The International Journal of Aviation Psychology, 19,* 182-199.

Wickens, C.D., Helleberg, J., Goh, J., Xu, X., & Horrey, W.J. (2001). *Pilot task management: Testing an attentional expected value model of visual scanning (ARL-01--14/NASA-01--7).* Savoy, IL*:* University of Illinois, Aviation Research Lab.

Wickens, C.D., & Long, J. (1994). Conformal Symbology, Attention Shifts, and the Head-Up Display. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 38,* 6-10.

Wickens, C.D., & Long, J. (1995). Object versus space-based models of visual attention: Implications for the design of head-up displays. *Journal of Experimental Psychology: Applied*, *1*, 179-193.

Wickens, C.D., & McCarley, J.S. (2007). *Applied Attention Theory*. Boca Raton, FL: CRC Press.