Readability of New Aviation Chart Symbology in Day and NVG Reading Conditions

Anthony S. Wagstaff; Terje Larsen

BACKGROUND: The Swedish Air Force (SwAF) conducted a study in 2010 to harmonize portrayal of aeronautical info (AI) on SwAF charts with NATO standards. A mismatch was found concerning vertical obstructions (VO). Norway regarded Sweden's existing symbology as a way to solve the problem of overcrowded air charts and the two countries started to cooperate. The result of this development was a new set of symbology for obstacles. The aim of this study was to test the readability of the new obstacle and power line symbols compared to the old symbols. We also wished to assess the readability in NVG illumination conditions, particularly regarding the new symbols compared to the old.

METHODS: In a randomized controlled study design, 21 volunteer military pilots from the Norwegian and Swedish Air Force were asked to perform tracking and chart-reading tests. The chart-reading test scored both errors and readability using a predefined score index. Subjective scoring was also done at the end of the test day.

RESULTS: Overall response time improved by approximately 20% using the new symbology and error rate decreased by approximately 30–90% where statistically significant differences were found.

DISCUSSION: The tracking test turned out to be too difficult due to several factors in the experimental design. Even though some caution should be shown in drawing conclusions from this study, the general trends seem well supported with the number of aircrew subjects we were able to recruit.

KEYWORDS: aviation medicine, aviation symbols, night vision goggles.

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Aeronautical charts are used in most types of aviation, military and civilian. Charts include not only positional information in the horizontal plane, but also information on variations in ground elevation and different types of vertical obstructions (VO). The correct perception of terrain and vertical obstructions is crucial to flight safety, particularly in low-flying operations. Such operations carry a high accident risk both in low-level military fast jet operations[1,6,10] and military helicopters,[17] as well as civilian helicopters.[1] The number of VOs on Norwegian charts has almost doubled during the last 10 yr. The same is probably true for many other countries, mainly due to the increase of mobile phones (3-G towers), windmills for electricity generation, and an expanding electrical delivery grid. The original NATO symbol for VO (antenna or mast) was designed during the 1950s. It had a design that fitted a chart with low information density. The charts of today have become cluttered due to the increase of information displayed, making the charts difficult to read. This is aggravated due to the symbols used to display this information. Aviators report this as a practical problem of readability, which also is supported by current research.[16] The use of night vision goggles (NVG) is an additional risk in low-level operations, further degrading visual performance,[3,4,7] which also has an impact on the reading of charts due to the green cockpit lighting (charts are read under their goggles, not through the goggles).

The Swedish Air Force (SwAF) conducted a study in 2010 to harmonize portrayal of aeronautical information (AI) on SwAF charts with NATO standards. A mismatch was found concerning VO. Norway regarded Sweden's existing symbology as a way to solve the problem of overcrowded charts and the two

From the Institute of Aviation Medicine, Norwegian Armed Forces Medical Service, and the Norwegian Military Geographical Service, Oslo, Norway.

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Address correspondence to: Anthony S. Wagstaff, Institute of Aviation Medicine, P.O. Box 14 Blindern, 0313 Oslo, Norway; anthony.wagstaff@flymed.uio.no.

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countries started a study to see if the Swedish symbology could be improved even more.

The original symbols for vertical obstructions have a large footprint area and height/elevation information is presented as numbers. This leaves a poor overview of information and a lack of ability to quickly evaluate where the highest obstacles are, particularly where many obstacles are close to one another.

Also, the readability of many of the chart symbols is degraded in NVG reading conditions. A blue-green lighting in the cockpit is necessary in order not to cause disturbances in the NVGs. In these low-light conditions, several symbols can be difficult to see, particularly those with a blue-green coloring, as blue-green coloring shows up poorly in green light due to ambient lighting influences on color discrimination.[13] An example is the symbol for power line, which is difficult to see, both due to shape and coloring.

A new proposed set of symbols together with adjustments of general cartography to optimize VOs were devised in order to both improve the speed of symbol recognition and to reduce reading errors. For low-flying aircraft such as helicopters and fast jets, any such improvement of readability could result in an improvement in flight safety.

The old and new proposed symbols are showed in **Fig. 1**. The new obstacle symbol is read as an analog dial: below 100 ft above ground level (AGL) the symbol consists of a red dot for a nonlighted obstacle and a red dot with a white center ("doughnut") for an obstacle which is lighted. For obstacles of 100 ft or over, a line similar to a clock arm is displayed as a clock analog, with 1 o'clock being a 100-ft obstacle, 2 o'clock being a 200-ft obstacle, and so on. The height of the obstacle above mean sea level (AMSL) is displayed as a small number on the right side of the obstacle symbol.

As seen in Fig. 1, power line and power span symbols were changed in order to improve recognition in daylight due to shape, and night-time (in NVG cockpit lighting) due to color and shape. In addition, general cartographic portrayal was changed for improved readability, including hypsometric tint, hill shade, contour lines, roads, AI, fonts, water display, and generalizations.

The aim of the study was to test the readability, particularly of the new obstacle and power line symbols compared to the old symbols, using both speed of recognition and error frequency as measures. We also wished to assess the readability in NVG illumination conditions, particularly regarding the new symbols compared to the old. An additional aim was to test the general readability of the charts, in an effort to assess any possible improvement of the changed cartographic portrayal.

Our hypotheses were:

1. The new symbology has better readability, measured by speed and accuracy, as compared to the old symbology.
2. The improved readability will be most apparent in cluttered situations and during NVG lighting conditions.

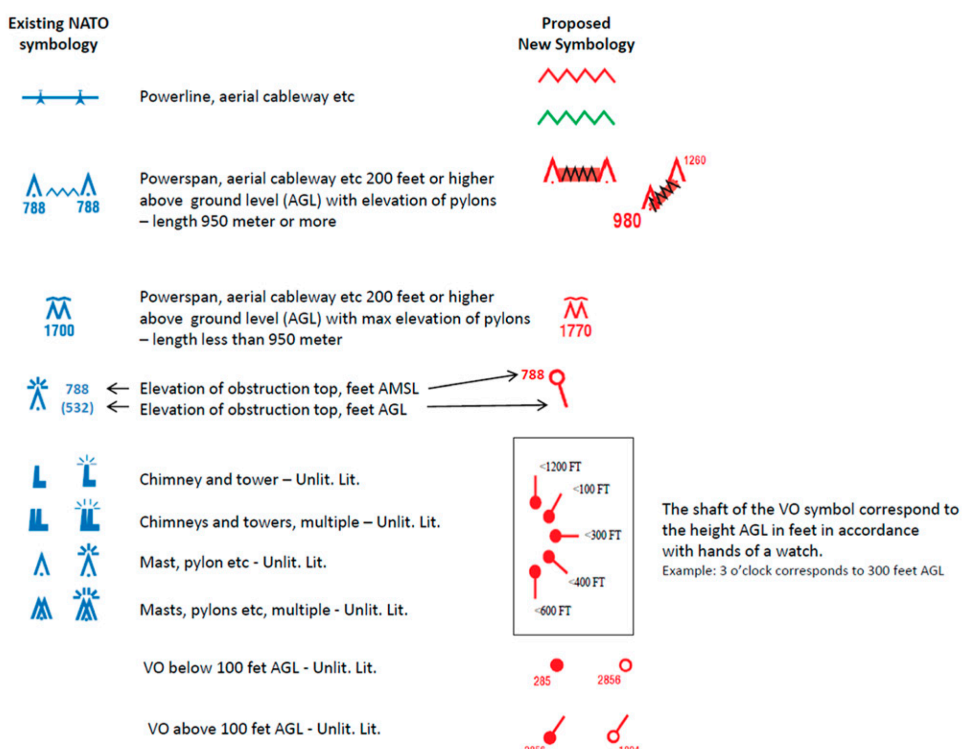

Fig. 1. Old (to the left) and new (to the right) chart symbology. The numbers denote height in feet. In the old/new pair on the bottom of the figure, the number in parentheses on the left and the number beside the obstacle symbols on the right shows AMSL. Height AGL for these symbols is shown in numbers on the left and in the clock dial fashion on the right.

METHODS

Subjects

In order to produce tests that would be valid and reliable, pilots and navigators from several aircraft types gave input, both in organized workshops and on a one-to-one basis. Visits to two helicopter squadrons (720 and 339 squadrons using Bell 412SP helicopters) and a fixed-wing transport squadron (335 squadron using C-130J aircraft) were arranged in order to discuss how to perform tests that had an operational validity. Information from discussions with crewmembers of other helicopter units and also fighter squadrons (F-16) was also used as input to the study.

There were 21 aircrew subject volunteers used; 14 Norwegian and 7 Swedish, all men with vision according to military aircrew standards. The aircrew had a wide range of experience, with a mean experience of 2200 flight hours (SD = 1948). Of the aircrew, 9 were fighter pilots, 10 were helicopter aircrew, and the last 2 had a varied experience. It was seen as an advantage to use aircrew from both these countries, since Swedish aircrew were familiar with a similar symbology used in the new chart, while Norwegian aircrew were familiar with the old/NATO-standard chart. The aircrew had varied experience with NVG operations, 14 with own operational experience, and 7 with little or no experience of NVG operations. The squadrons themselves selected the participating subjects based on aircrew availability on the specific dates.

No specific approvals were necessary according to national rules, since no medical or physiological data was collected, and all results were entered and analyzed in nonidentifiable forms. Informed consent was, however, obtained from all subjects.

Materials

A tracking test was devised in order to test the readability of the new charts, particularly in relation to improved coloring and terrain lines. In the preparation for this test, four low-level routes were flown by a Bell 412SP helicopter carrying a high definition video camera filming forward through a 120° lens. The tracks were GPS-recorded, allowing an exact replication of the route flown. The tracks were flown in routes with similar density of landmarks, over rural areas in northern Norway. The flights were presented in the experimental condition by video projection onto a screen sized approximately 1.5 × 1.5 m. A horizontal situation indicator as well as a speed indicator was shown in the lower right-hand corner of the screen (see **Fig. 2**). The test subjects were required to follow the terrain and instruments on the video while reading the paper chart on the desk in front of him. The chart had a marked point from where the video of the flight started. On indication from a short audio signal, at intervals of approximately 1 min, the subject was instructed to mark waypoints with a pen on the chart to indicate the track that was being flown on the video.

The video film was not viewed through night vision goggles, as this was deemed impractical and the main task was the readability of the charts. The instruments were not subject to NVG lighting as can be seen in the right-hand portion of Fig. 2, since this made them very difficult to read on the video.

A chart reading test was also devised. The chart reading test used test questions with timed answers, for readability of key information aspects of each symbol. The questions were devised to test aspects of the different symbology which had come up during the discussions with pilots of different types of aircraft, as described earlier. Thus, the questions tested the following aspects of the old and new symbology:

- Readability of the simple form of the two symbol types (old and new) for obstacle AGL.
- Readability of the two symbol types (old and new) for lighted obstacles.
- Readability of the two symbol types for obstacles (old and new) when reading upside down.
- Readability of the two symbol types with AMSL readings.
- Readability of the two symbol types (old and new) for power lines.
- Readability of the two symbol types (old and new) for power spans.
- Readability of the two symbol types (old and new) in cluttered conditions (many symbols close together).

Similarly to the tracking test, the old and new chart sections showed identical areas in Norway, in two versions, using old and new symbology, respectively.

Readability was measured by defining two separate variables:

1. The number of errors as a percentage of possible correct answers; and
2. The speed of response time in seconds, measured by the time for a correct response.

The subjects were instructed that both speed and accuracy were equally important when performing the tasks.

The NVG lighting conditions consisted of blue-green lighting set to a light level of 1 lx (equal to 0.09 footcandles) according to military standard for NVG-compatible lighting. The subjects did not use night vision goggles during the experiments, as the reading of maps in NVG operations is performed by looking under the goggles.

Procedure

The subjects were each assigned to one of two experimental days (depending on the availability of the subject). The experiment started with a briefing of the two chart types, emphasizing the differences and symbol meanings. The participants were given 2 h, including the briefing, to familiarize themselves with the charts and to make sure they were well aware of the meaning of all the symbols in each chart type. After this, the subjects were randomized into two groups. Each group was assigned either to the tracking test or the chart reading test described below. After lunch, the groups changed tests. During both the tracking test and the chart reading test, all subjects

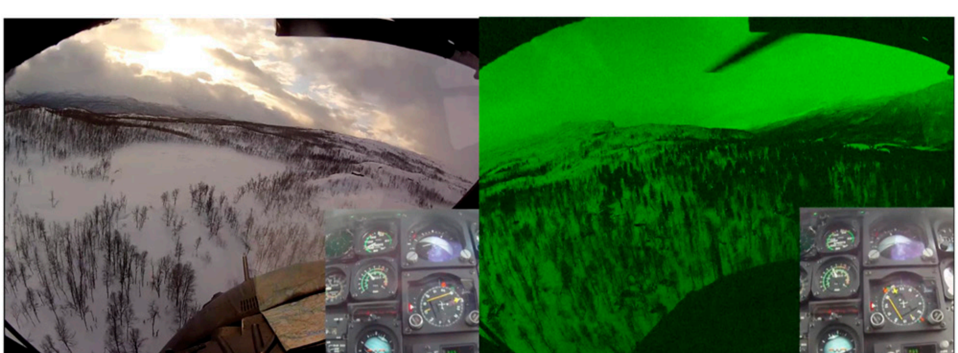

Fig. 2. Video view for tracking test: daylight and NVG conditions.

were exposed to new and old charts in both daylight (classroom lighting) and NVG lighting conditions.

The experimental set up followed a balanced design in relation to the sequence of charts and the order of NVG vs. daylight conditions. In other words, half of the subjects were exposed to the NVG condition first, the other half the daylight lighting condition. Similarly, for each lighting condition, half the subjects were exposed to the old charts first, the other half the new charts first. The chart sections for old and new charts were selected using same quality printed charts. The sections were selected and prepared by chart specialists, and the old chart sections used for the test were for identical areas as the new chart sections. No chart sections in any version (new or old) were reused for any subject, in order to avoid learning effects regarding a particular chart. The balance in these experimental conditions was designed in order to rule out any systematic bias due to learning or other effect.

The chart reading tests were conducted by an experienced pilot instructing and monitoring each test subject one-on-one for each question. Each subject was instructed to answer each question relating to a chart section, timing each answer with a stop watch, starting from the uncovering of the chart section and ending when the response was given.

All the subjects were asked to also subjectively score their preferred chart according to different aspects and attributes. This scoring was done immediately after completing the tests, each subject having spent an equal amount of time with each chart. In order to avoid the subjects influencing each other's scores, the subjects were told not to discuss the experiment until after the subjective scoring was completed at the end of the day.

Statistical Analysis

The tracking tests were scored using the mean deviation of the waypoints between the actual route flown and the waypoints noted down by the subjects. When evaluating the chart reading test, we used separate scores for speed (number of seconds for completion of task) and error rate (number of errors as percentage of the total number of answers). Each defined separate aspect of the new symbology was analyzed as a stand-alone analysis, using Student's *t*-test and Bonferroni post hoc correction for multiple tests in a family of hypotheses. The color change optimization for the new symbology was analyzed as a single effect across all experiments by comparing the change in scores between day and NVG conditions using the old symbology with the change in scores between day and NVG conditions using the new symbology.

All data were entered into an Excel worksheet. After controlling for normality, we used Student's 2-tailed t-test with $P \leq 0.05$ as significance and $P \leq 0.01$ as highly significant. Bonferroni correction was performed where stated.

RESULTS

The tracking test did not give conclusive results. The mean deviations from the actual route were large under both daytime and NVG conditions, for both new and old type charts, showing that few were able to follow the track. Early errors occurred nearly invariably and the ensuing error-upon-error situation made further analysis meaningless. There were no clear differences noted between the groups and the test subjects reported the session as a very intense and frustrating mental exercise.

For the overall results of the chart reading tasks, see **Table I**. The mean times for correct answers were shorter for all tasks except the task involving AMSL. A statistically significant improvement in speed of reading was found for obstacle symbols with lights. A statistically significant improvement in error rate was also found in counting obstacle symbols with lights, as well as for power spans. A highly significant improvement in error rate was found with the counting of power lines. A highly significant improvement in error rate was also found in the task with the obstacle symbols in the cluttered scenario.

Surprisingly, the task involving the AMSL reading showed a significant reduction in the speed of reading for the new symbology compared to the old (increased time of correct answer). The speed of response, measured in time (seconds), was significantly improved for the new charts in the NVG reading

Table I. Total Results of Chart-Reading Tasks for Speed (Response Time in Seconds) and Error Rate (Number of Errors as Percentage of the Total Number of Answers).

TASK	OLD MAP	NEW MAP
Localize and note height for highest obstacle AGL on map		
Speed	56.6 (8.5)	51.5 (11.4)
Error rate	2.0 (4.3)	3.5 (3.9)
How many obstacle symbols under 100 ft AGL have lights?		
Speed	68.2 (7.2)	45.1 (10.9)*
Error rate	19.3 (7.4)	12.6 (8.9)
How many lighted obstacles can you find on this map?		
Speed	66.2 (12.8)	44.9 (9.4)
Error rate	22.5 (8.0)	7.0 (6.0)*
Upside down: How high is the highest obstacle in feet?		
Speed	70.9 (16.8)	66.5 (21.3)
Error rate	7.0 (8.6)	13.0 (10.6)
How many obstacle symbols > 800 ft AMSL do you see on this map section?		
Speed	91.8 (14.2)	142.3 (26.3)*
Error rate	14.5 (6.8)	20.2 (8.0)
You are flying in a straigh line X to Y. How many powerlines must you cross?		
Speed	37.0 (8.3)	23.7 (4.3)
Error rate	27.3 (7.6)	11.0 (4.3)**
How many spans do you see in this map section?		
Speed	88.0 (11.2)	72.8 (10.4)
Error rate	26.7 (6.8)	10.3 (7.2)*
Cluttered: How many symbols are visible on Tromsø Island?		
Speed	50.0 (7.1)	48.7 (8.0)
Error rate	6.5 (3.8)	0.5 (1.4)**

$N = 21$; 95% confidence number shown in brackets.
* *P*-value 0.05 or less; ** *P*-value 0.01 or less, after Bonferroni correction for family of hypotheses.

conditions and overall reading conditions (see **Fig. 3**). The increase in improved performance regarding errors was significant for the day condition, but did not reach significance for the night or overall performance, as shown in **Fig. 4**. The subjective score for the old vs. new chart for the 21 military pilots is shown in **Table II**. We found no statistically significant differences between results for Swedish and Norwegian air crew.

DISCUSSION

The tracking test did not give conclusive results. The mean deviations from the actual route were relatively large under both daytime and NVG conditions, for both new and old type charts, showing that few, if any, aircrew were actually able to follow the track. There were no significant differences noted between the groups. Low-level navigation is a difficult task, with misperceptions being relatively common.[17] The lack of opportunity to turn your head for location of landmarks or having a full instrument display in our experiment augmented the difficulty of the navigational task. It may be that this task was too difficult and that slight differences would be easier to detect if the subjects had more landmarks along the route, or simply an easier or more familiar flight route. However, the 2–3 h spent performing this test gave the subjects additional time to become more comfortable in reading the two chart types, thus providing a better basis for the other tests and, in particular, the subjective scoring.

When asked to localize and note the height for the highest obstacle AGL on the chart reading test using uncluttered charts, there was no significant difference between the old and new symbols. This shows that we found no measurable difference in the readability for the old and new symbols in uncluttered charts. Both the old and new obstacle symbols are, however, relatively easy to perceive on their own. Although we are not aware of other experimental studies with these particular symbol types, laboratory experiments with similar symbols suggest that both lines with different orientations (new symbol) and numerical values (old symbol) in themselves carry sufficient information for effective perception in an uncluttered environment.[9]

The symbol for a lighted obstacle seems intuitive and efficient for rapid viewing. Even though the lighting symbol (white dot in center of symbol) takes no extra space from the chart, it is easier to see quickly than the old lighting symbol shown as a "flash effect" above the old obstacle symbol, taking extra space on the chart. Here, the white/red contrast of this chart symbol may be decisive for the significant findings both in speed of reading and error rate.[14]

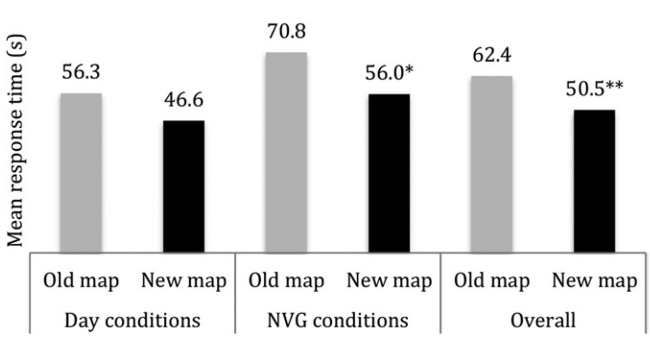

Fig. 3. Mean time for correct responses for the old and new chart types for day, night, and overall, respectively, for 21 military pilots. *P-value ≤ 0.05, **P-value ≤ 0.01.

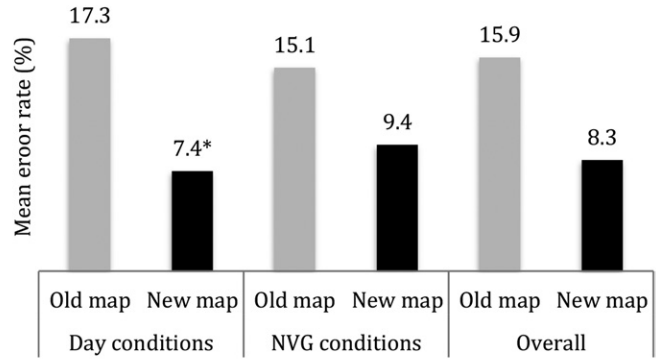

Fig. 4. Mean error rate for the old and new chart types for day, night, and overall, respectively, for 21 military pilots. *P-value ≤ 0.05.

During upside down reading of charts, the results show no significant difference between old and new symbols, neither for speed or error rate. One could suspect that the new symbols would perform inferiorly in these conditions, since upside-down reading of a symbol that requires a north-south reference to be read correctly might give rise to error. However, reading numbers upside-down is also a challenge when using the old symbols, which include two sets of numericals.

When testing charts with cluttered areas, like Tromsø Island, judging how many obstacle symbols are visible, the new symbols performed better, with a highly significant effect for error rate being reduced to less than one-fifth of the rate using the old chart. This result shows the effect of clutter on symbology perception, which is well known.[12,16] However, as hypothesized, our results show that the new symbols are easier to pick out in a cluttered situation, maybe because the simplicity and uniqueness of the symbol to a greater extent triggers low-level perceptual detectors.[11] It might be added that Tromsoe Island has less than 10 obstacle symbols on an area of 21 km^2 and, therefore, is probably less cluttered than many larger city areas.

When testing for AMSL reading, results show that the speed score was better for the old symbols. This is a rather surprising result at first glance. However, the AMSL height in the new symbol set is given in numbers beside the symbol and not as a clock-dial analog symbol. These numbers have smaller print than in the old symbols, which might be the reason for the results, since contrast sensitivity increases rapidly with size, particularly near the limit of acuity,[14] and degraded contrast sensitivity slows performance.[15] Because of these findings, the AMSL-number for obstacles on later chart editions have received a different font and size than the AMSL-number for land features.

The results regarding power lines show highly significant performance improvements for the new symbols regarding a reduction of error rate. The error rate for power spans also

Table II. Subjective Preferences Regarding Old or New Maps, According to the Different Aspects.

NO. OF AIRCREW WITH PREFERENCE	OLD MAP	NEW MAP	NO PREFERENCE
Obstacle	21	0	0
Obstacle NVG lighting	19	2	0
Powerline	21	0	0
Powerline NVG lighting	21	0	0
Powerspan	18	0	3
Powerspan NVG lighting	16	0	4
Obstacle alone	15	4	2
Obstacle alone NVG lighting	16	4	1
Obstacle group	21	0	0
Obstacle group NVG lighting	21	0	0

$N = 21$.

shows a significant improvement. This shows that the improvement efforts for these symbols seem to have been successful for the new chart type, being a combination of both thicker zig-zag lines acting as an attentional flag even in background clutter, and improving the color from blue in the old symbols to green and red with black coloring integrated for better NVG conditions.

When looking at Fig. 3 and Fig. 4, the differences between scores for all questions combined are shown. The general trend for all measures is an improvement for the new charts compared with the old. However, the difference only reaches significance for speed of reading (time for correct response) for NVG and overall reading conditions, and error rate for day reading conditions. It is unclear whether this is due to real differences for day and night reading conditions or statistical errors. The large variability in error rates as seen in Table I may mean that the number of subjects was too small for this measure, causing type 2 error. Another question is how the different tasks and other factors may have affected the subjects regarding the trade-off between speed of reading and error avoidance (accuracy).[5] Although the subjects were instructed that both speed and accuracy were equally important when performing a task, different subjects may have weighted these aspects differently,[2] also between tasks. This may have caused some tasks to yield significant differences for errors, others for speed.

When evaluating strengths and limitations of this study, it should be noted that different aircrew exhibited a wide range of performance in our experimental setting, although most are accustomed to chart reading and judging terrain. They may also be biased toward the symbols that they already know and are used to, although similarities in the Swedish and Norwegian group results indicate that this was not an important effect. A general subjective bias may be caused by an analog to the so-called "Hawthorne effect,"[8] which describes that changing a variable or introducing a novelty increases performance in itself. If this were an important factor here, one would also expect that results for the Swedish and Norwegian aircrews would differ clearly, which they did not. We did achieve the number of subjects we planned (planned: at least $N = 20$), being realistic regarding the turn-up given the busy schedules of our aircrew. A larger number of subjects would probably be able to clarify some of the tests to a larger extent due to greater statistical power, but realistically more subjects would be difficult to recruit considering time constraints on operational aircrew. Even though some caution should be shown in drawing conclusions from this study, the general trends seem well supported with the number of aircrew subjects we were able to recruit. The strengths of the study include a general trend that is clear across parameters and also that the objective and subjective test results support each other. In addition, the fact that the test population consisted of aircrew and that it included participants from both Sweden and Norway probably is important in supporting the validity of the study.

In conclusion, our findings can be summarized as follows:

1. Our results indicate that the new obstacle symbols were similar for readability as the old ones, when read in uncluttered chart conditions, including upside-down reading.
2. The new obstacle symbols with lights offered significantly better readability in our tests.
3. The new obstacle symbols in groups offered significantly better readability according to our tests as well, and errors were reduced to less than one-fifth of the errors with the old symbols when reading in cluttered conditions.
4. AMSL readings were less efficient using the new symbols. This might be due to the font size of the text, which was smaller on the new symbols.
5. We found that the new power line and span symbols yielded significantly better performance in error rate.
6. The subjective preferences of the Norwegian and Swedish aircrew support the objective findings.

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Authors and affiliations: Anthony S. Wagstaff, M.D., Ph.D., Norwegian Armed Forces Institute of Aviation Medicine, Oslo, Norway, and Terje Larsen, Capt., RNoAF, Norwegian Military Geographical Service, Oslo, Norway.

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