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Reminding without disturbing: a soft visual cues attention support design for an air traffic control conflict detection visualisation

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ABSTRACT

Attention guidance can mitigate problems with missed information in control room environments. However, it might distract attention from things considered more important by the operator. The concept Soft Visual Cues has been proposed to address this. The cues shall be a reminder when looked at during routine visual scanning, without unintentionally attracting attention. In this study, Air Traffic Controllers tested and assessed a Soft Visual Cues design based on the rotation of a symbol in an aircraft conflict visualisation tool through a series of real-time human-in-the-loop simulations. Soft Visual Cue aspects, such as perceived softness and risk for unintended attention caused by the rotation, were evaluated. Feedback from the controllers, supported by eye gaze data, showed that the rotation did not attract unwanted attention. Overall, the results from the validation show that the proposed design was considered to fulfil its purpose in an operationally relevant environment, that the concept should be possible to use in similar settings, and that the rotated symbol was generally considered a good Soft Visual Cue by the participants. Further, the results indicate the importance of tailoring the design to fit the targeted visual environment and domain specific needs to find the right level of softness.

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KEYWORDS
Soft visual cues; adaptive visualisation; attention guidance; air traffic control

1. Introduction and background

In an information-rich environment with high visual load, information can easily be missed. When working with real-time, time-critical processes in a high-stakes environment, such as Air Traffic Control (ATC), this can be a serious issue. One way to mitigate the risks is to use attention support. However, if attention is drawn *to* something that may have been missed, it inherently also means drawing attention *from* something else. If the situation requires urgent attention and the operator is indeed working on something less urgent, a very strong mechanism for drawing attention, an alarm, is appropriate. However, in contrast, if attention guidance is used for directing attention to something important, but not (yet) alarmingly urgent, or to something that improves the process rather than being essential to it, then the support system needs to know what it is drawing attention from. If not, it might draw attention from something with a higher priority for the operator. A solution to mitigate this risk, the concept of Soft Visual Cues (SVC), was proposed by Nylin, Lundberg, and Johansson (2020). The basic idea in the concept was to make a change of some property of a graphical object, thus making it easy to recognise and distinguish from other similar, unchanged, objects when visually scanning the area, yet not actively drawing attention to it. A prerequisite for this is that the users, like Air Traffic Controllers (ATCOs), are trained to regularly scan areas of interest and obtain accustomed scan patterns. Thus testing and evaluating an SVC design requires subjects who have highly trained visual scanning behaviour, performing a realistic task in their familiar work environment. Concepts such as this, to gently point at something, are important to achieve the goals of the EASA AI Roadmap, especially AI level 2B, Collaborative Human AI Teaming (EASA 2023).

Our main goal with this study was to explore how ATCOs experienced the SVC design proposed by Nylin, Lundberg, and Johansson (2020) for an ATC conflict visualisation tool, the Conflict and Risk Display (CARD) when implemented in a real-time environment, and to what extent the ATCOs considered it to fulfil its purpose of being a soft visual cue. Further, we investigated the ATCOs opinions about the SVC in the CARD with respect to the different roles of the Executive Controller (EC) and the Planner Controller

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(PC). The results from Nylin, Lundberg, and Johansson (2020) showed that a rotation of the conflict symbol was the most promising design. Since it was not conclusive from those results whether an immediate or gradual rotation was preferable, both were tested in this study.

This study focuses on the appropriate design and behaviour of an SVC for experienced ATCOs in a realistic operational context. A delimitation of our study is that we used a basic algorithm to determine the appropriate cue state. Current rapid advances in artificial intelligence make it likely that more advanced algorithms that can use the SVC concept can be developed in the near future.

During one week, a series of small-scale simulations were conducted in LFV's (Air Navigation Services of Sweden) Narsim Air Traffic Management (ATM) research simulator (NLR 2022) with Narsim's Conflict Window, which is the equivalent to the CARD used in the operational environment. Eye-tracking glasses were used to collect gaze data. The ATCO HMI was analysed and compared with the eye gaze data in real time by a purpose-built SVC system to keep track of if the conflict symbols were looked at. The analysis of the HMI was performed by detecting the Conflict Window objects in the video output stream from the simulator. If the ATCO did not look at the conflict object for 30 s, the graphical object was modified (rotated) before being sent to the screen. By this approach of only working with the objects in the video stream, no integration with the simulated ATM system was needed.

During the week, 18 simulation runs with nine ATCOs were completed. The data collected was analysed using a mixed method approach, where the focus was on the ATCOs experience gathered from the qualitative data, supported by quantitative, eye gaze, data.

To summarise, the main goal of the study was to explore:

- how ATCOs experienced the SVC design proposed by Nylin, Lundberg, and Johansson (2020) for an ATC conflict visualisation tool, the Conflict and Risk Display (CARD) when implemented in a real-time environment,
- to what extent the ATCOs considered it to fulfil its purpose of being a soft visual cue.

Overall, the qualitative results showed that the ATCOs considered the design to fulfil the purpose of the SVC concept and that it could work in a realistic environment. The gaze tracking data indicates the cues were recognised when looked at, but did not draw attention from something else. This finding was strengthened by that they were not considered intrusive by the ATCOs. Our data did not indicate any difference between gradual and immediate rotation.

The knowledge gained from the ATCOs feedback and that it could be shown that the implemented SVC design could work in a realistic environment is the main contribution of this work. By this, the concept adds a new tool to the attention support design toolbox that fills a gap between subtle gaze directions and attention guidance. The experiment setup contributes to how similar concepts can be tested in the future.

1.1. Air traffic control

The SVC concept was specifically developed for graphical user interfaces intended for expert users, such as ATCOs, who are trained to regularly scan areas of interest and thus can be assumed to notice attention guidance that is softer than alarms. In this case, it is the environment in one specific branch of ATC, area control (ACC) or en route control, that is targeted. The area control is performed in the airspace between 9500 and 66,000 feet (referring to Swedish conditions).

The work of area control ATCOs is often carried out in pairs, where a Planner Controller (PC) makes plans for the traffic approaching the sector, coordinates with adjacent sectors, and searches for future conflicts. The Executive Controller (EC) searches for conflicts on a shorter time horizon and implements solutions by issuing instructions, clearances, to the aircraft. Whether the work is performed in pairs, or if both roles are handled by a single ATCO, is determined by the anticipated workload in the controlled sector. The controller working position is dominated by the Air Situation Display (ASD), where surveillance data depict the aircraft's position. Each aircraft symbol has associated flight plan data and current flight information such as altitude and speed presented in a label. In the ASD, area control ATCOs have several tools, such as vectors for measuring distances, flight legs, prediction lines, and the separation monitoring tool to support their work. One of the most important tools is the Medium Term Conflict Detection (MTCD), an automated conflict detection system that identifies conflicts between aircraft trajectories up to 30 min ahead. Associated with the MTCD is the visualisation of the identified conflicts, the Conflict and Risk Display (CARD). Note that conflicts in this sense are aircraft that will come closer to each other than a certain distance, but not necessarily below separation minima. The CARD displays aircraft that are calculated to be within 10 nautical miles (NM) from each other, while stipulated separation minima is 5 NM. Hence, not all conflicts shown in the CARD will trigger a resolution action from the ATCO. The ASD also contains

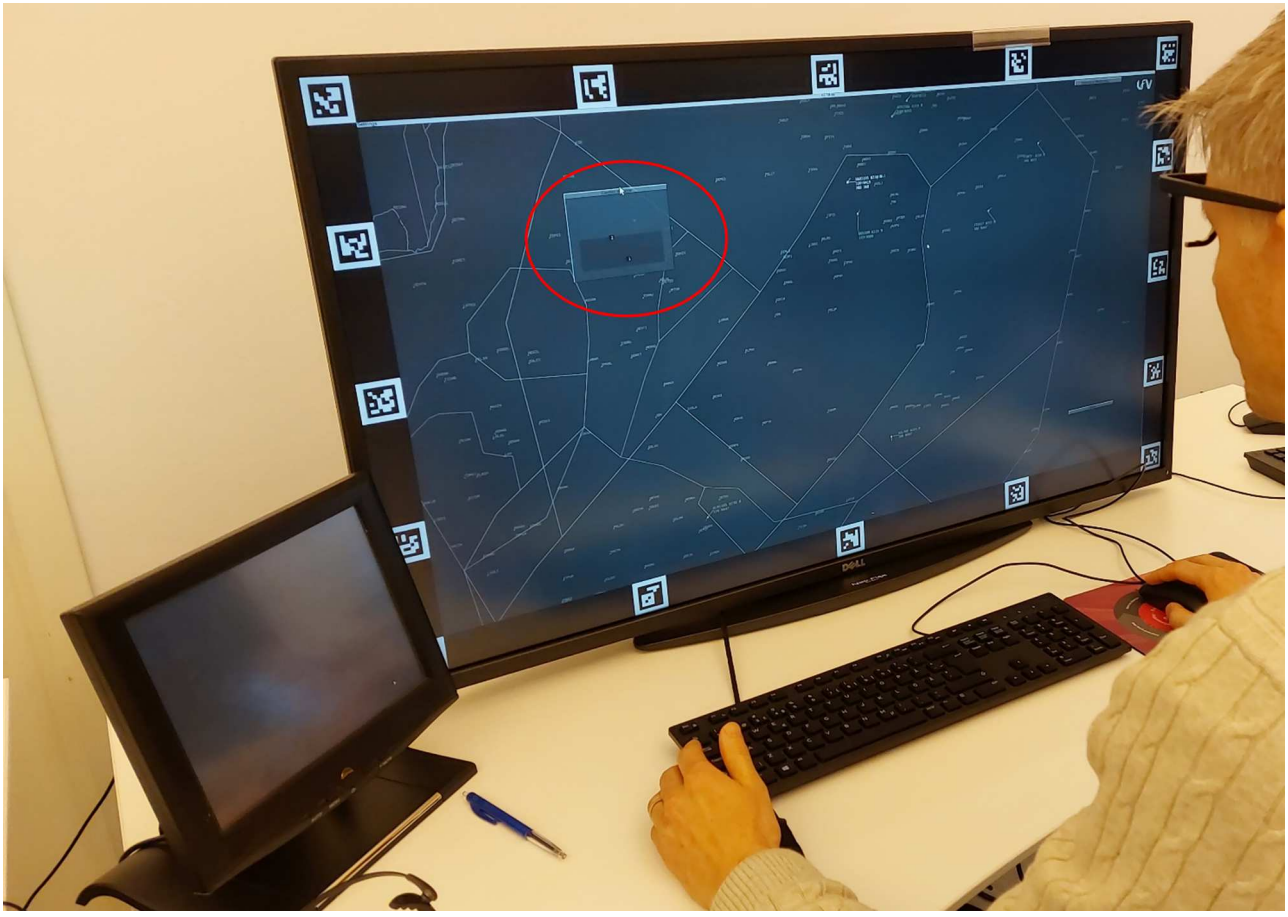

Figure 1. The controller working position in the simulator. The red ring in the main screen's air situation display (ASD) highlights the conflict visualisation window, see Figure 3 for a zoomed in view. The slightly darker grey area in the middle of the ASD is the sector in which the ATCO has the responsibility for controlling the air traffic. The QR code in the frame is to enable the eye tracking system to correlate the gaze coordinates with the screen coordinates. The small screen in the left lower corner is for the voice communication system.

additional information such as navigation points, sector borders, and much more. Figure 1 shows an overview of the controller working position of the simulator used in the study. A detailed image of the CARD (the Conflict Window of the simulator used in this study), is presented in Figure 3.

1.2. Attention support

The SVC concept was proposed in Nylin, Lundberg, and Johansson (2020) as a complement to the more salient and active forms of attention support, such as alarms, Attention Guidance (AG) and Subtle Gaze Direction (SGD). These attention support concepts aim at actively guiding attention. Alarms are very salient and need no further explanation. Attention guidance have been studied in various domains, for example in ATC (Ohneiser, Adamala, and Salomea 2021; Ohneiser, Gürlük, and Jauer 2019; Rataj et al. 2021; Teutsch et al. 2022), vehicle driving (Tamura et al. 2021) and studies of cockpit tasks (Durant et al. 2022) (though simulating human agents). While attention guidance actively attracts the user's attention with the user being aware of the guidance, the SGD guides attention silently – the user shall be unaware of the guidance (Bailey et al. 2009; Grogorick et al. 2017; Paul and Ragan 2020; Sridharan and Bailey 2015).

With advances in AI, there is a need for automation to communicate in a more collaborative manner with operators. In the EASA AI masterplan (EASA 2023), especially level 2B of AI support – human AI teaming, requires new solutions in which attention guidance is less intrusive. For less urgent situations, an AI needs to be able to gently point things out to the ATCO without disturbing too much.

The focus in this study is on on-screen attention support, from a system to a user, but there are also other environments where attention support can be applied. For example, the development of virtual reality has created a need for guiding in immersive environments

(Asteriou et al. 2023; Lange et al. 2020; Wen, Ali, and Lu 2022), and Tamura et al. used a driving agent with eyes that guided attention in a self-driving car (Tamura et al. 2021). Another, screen-based, example is the development of attention guidance in remote meetings to share attention remotely between a presenter and other participants (Langner, Toreini, and Maedche 2022).

The SVC concept was designed to support attention by relying on the user's gaze patterns to determine its state, and designed so that the cue is seen only when looked directly at. Hence, it is important not to catch attention by accident. For example, sudden movements are quickly detected by peripheral vision (Bakker, Hausen, and Selker 2016; Bartram, Ware, and Calvert 2003). Some changes in the attributes of a graphical element are more easily detected than others. Changes that constitute the presence of something work better than the absence of a property – a Q among O:s is much easier to detect than an O among Q:s. However, multiple changes though may distract the detection and lead to false perceptions (Treisman 1986). Wolfe and Horowitz (2017) listed several attributes and how well they stand out. Orientation, or rotation as denoted here, is one of the attributes that stands out the most and was the attribute change that was considered the most suitable for SVC in Nylin, Lundberg, and Johansson (2020).

1.3. Attention support in ATC

ATC working positions are visually intense, and information can easily be missed (Shorrock 2005, 2007), even by just a small distraction (Lundberg, Nylin, and Josefsson 2016). Attention in relation to the visualisation of the MTCD (and the CARD) was discussed in Lundberg et al. (2014). Looking through incident reports and talking to ATCOs have confirmed that this is still an issue.

There are some examples of attention guidance for ATC in an en route environment. Ohneiser, Gürlük, and Jauer (2019) used attention guidance for the transfer of responsibility of aircraft between ATCOs and conflict information. The attention guidance was tested in real-time human-in-the-loop simulations and was well received, even if concerns were reported on one occasion about the risk of drawing attention away from other important tasks. Rataj et al. (2021) aimed for attention guidance in future, highly automated ATM systems where the ATCO had a less active role. Their approach was to compare where the ATCOs attention should be, based on the need of the system, and the actual gaze. If there was a mismatch, attention guidance was used to help the ATCO to focus on the most relevant information. The roles of both EC and PC in en route environment, as well as approach controllers, were addressed. Ohneiser, Gürlük, and Jauer (2019) used visual cues of different salience which were also referred to by Rataj et al. (2021). The cues were used with the aircraft labels and aircraft symbols, the first level cue was a box around the label, the second level was a grey semi-transparent circle around the aircraft symbol, and in the third escalation level, the circle had a brighter frame. For example, medium term conflicts were considered less urgent than short term conflicts, but more urgent than short term conflicts. Note that the even if the cues were of different salience, they were all intended to *guide* attention. If a situation was recognised but not solved, a new cue was issued. Some different designs for short term conflict alert notifications were evaluated by Imbert et al. (2014). One of their overarching conclusions was that the power of the design must be balanced relative to its contextual importance, even if their goal was to catch attention. Hameed et al. (2007) used tactile cues in combination with on-screen shape changes to increase detection the rate of the visual cues. However, it was not combined with any active tracking of the attention of the users, and the participants consisted of students without ATC experience.

Attention guidance has also been studied in an ATC tower environment, for example, by Teutsch et al. (2022), Papenfuss and Friedrich (2016), and Manske and Schier (2015). However, the tower environment differs from the en route environment. The tower contains a 360 degree view in combination with multiple separate support systems, while the en route environment is concentrated to one main screen, complemented with a few secondary screens, where all visual information is gathered. Teutsch et al. (2022) used augmented reality in the form of a Hololens to address the challenge of covering large areas.

To conclude, some attention support research has been performed within ATC, mainly in en-route environment, but it is not extensive. Most of the en route studies address conflict detection, but none of them have included the concept of, or a concept similar to, SVC.

2. Method

The study was performed using a convergent mixed method approach. Data was collected during a series of real-time, human-in-the-loop simulations of a real area control sector using three data collection procedures. (1) Qualitative data was collected in semi-structured post-simulation interviews (debriefings)

with the ATCOs, to capture their experience of the SVCs. (2) Post-run questionnaires had close-ended statements about the SVCs and the fit for purpose of the gradual and the immediate rotations respectively. The questionnaires were similar to the ones used in Nylin, Lundberg, and Johansson (2020) and each of the ratings were made by indicating to what extent they agreed to certain statements on a 10 step scale for intrusiveness and a 12 step scale for fit for purpose. (3) Eye gaze data was recorded to assess if attention was drawn to the symbol by the SVC, and to calculate if there was any difference in time-to-seen between gradual and immediate rotation, thus complementing the questionnaire data and answers from the debriefings. The debriefing comments, i.e. the ATCO experience, were grouped and analysed following the interview topic structure. The time from initiation of rotation until the SVC was seen was calculated from the SVC system logs. Data was analysed to assess if the rotation attracted attention and the results were compared with the ratings of intrusiveness from the post-run questionnaires and the statements from the ATCOs from the debriefings. The time-to-seen was also analysed to establish whether there was any difference between gradual and immediate rotation. Since this study relies on operators to use gaze patterns that are part of their ATCO expertise, ecological validity of the traffic situation and the visual work environment were central to the study design.

2.1. Ethical considerations

An application for ethical approval was submitted to the Swedish Ethical Review Authority in a similar project using eye-tracking to retrieve gaze data from air traffic controllers (Nylin et al. 2022). The verdict was that no ethical approval was required for this type of study. Based on that verdict, it was concluded that no ethical approval was needed.

All participants were informed before starting the experiments about their rights as participants and signed an informed consent form to establish that they participated voluntarily and could terminate their participation at any time without having to justify why (see also Section 2.7).

2.2. Design and development of the SVC

The SVC design was based on the result in Nylin, Lundberg, and Johansson (2020), where different SVC designs were evaluated, Figure 2. Of these, a rotation of the square that represents a conflict in the CARD was found to best fulfil the purpose of SVC.

During the evaluation in Nylin, Lundberg, and Johansson (2020), a gradual rotation was used to avoid catching peripheral attention. However, it was not conclusive from the results whether an immediate or a gradual rotation was to prefer. The doubts raised were related to whether the gradual rotation added any value, and another comment was that it might feel a little bit ambiguous – shall it be noticed or not? Hence, both variants were evaluated in this study, though it was limited to having or not having a gradual rotation because evaluating different rotation speeds was not the purpose. The speed of the gradual rotation of the symbol was tried out by the research team during the preparations of the simulation to find a speed where the rotation was not perceived as attracting peripheral attention, yet making it an effective change. This resulted in a rotation speed of ten degrees per second, or a rotation time of 4.5 s to rotate the square 45 degrees. Figure 3 shows three conflict symbols in the Conflict Window (the simulator's equivalent to the CARD) with one of the symbols having been rotated.

2.3. Simulation and scenario design

The simulations were performed at the LFV Research and Innovation department's simulation premises at Malmö Airport using the Narsim ATM simulator (NLR 2022). The simulated traffic was based on historical traffic data in an Area Control (ACC) sector in Swedish airspace. The density and the complexity of the traffic were adapted to match single ATCO operation in the sector. The traffic was controlled by a simulator pilot. Interaction with surrounding sectors, such as

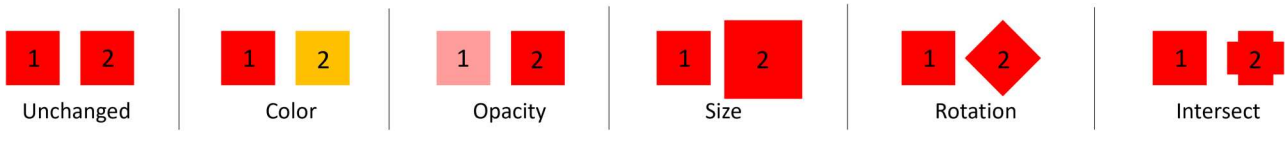

Figure 2. The design alternatives evaluated in Nylin, Lundberg, and Johansson (2020). From left to right: *no change*, *change in colour*, *change in opacity*, *increased size*, *rotation*, and *addition of an intersecting element*. Note that for opacity, it was the not-missed symbols that were toned down to make the missed symbol stand out. Rotation was found to be the design best fit for purpose of being a Soft Visual Cue.

Figure 3. This screenshot shows the conflict window. Each square represents a conflict with an identifying number, shortest calculated distances is on the *y*-axis (maximum 10 nautical miles) and time to when it occurs is at the *x*-axis (maximum 20 min). The darker grey area depicts minimum separation, which is 5 nautical miles. The conflict symbol with id 2 has been rotated.

transfer of control of flights to and from the simulated sector was provided by a rest-of-the-world (ROW) position, Figure 4.

2.4. Participants

The evaluation of an SVC design ideally draws on participants with highly trained-in visual scan patterns, performing tasks with varying degrees of urgency and importance. Thus, although in limited availability, operational experts are the ideal subjects if a work environment is also available that is similar to their actual work environment. Since the main purpose of the study was to evaluate the SVC design in the applied context from the experience of subject matter experts, it was essential to carry out the study with operational ATCOs with experience in using the conflict and risk display. The requirement for operational ATCOs as participants, of which there is no excess, limited the number of ATCOs available. Eye-tracking glasses without correction for eyesight issues were used in the study, hence, only participants who did not need glasses could participate in the study.

Nevertheless, we were able to recruit a total of ten ATCOs for participation in the study, whereof nine finally participated. One cancelled the participation since the Glasses were considered uncomfortable and disturbing (note: in accordance with the informed consent, the reason was not asked for, but expressed spontaneously by the participant). The recruitment was carried out through the Air Traffic Control Centres (ATCC) ordinary staff planning, which means that the sample was based on ATCO availability. All participants held valid ATCO ratings at the Malmö ATCC. There were 2 male and 7 female participants with an average of 20.2 years of experience (std dev 7.7 and median 21.0) and a mean age of 45.3 (std dev 8.5 and median 45). They all participated during office working hours in their normal work schedule.

Each participant performed two exercise runs, each with a specific traffic scenario, scenario A or B. The scenarios lasted 40–45 min, depending on how the traffic

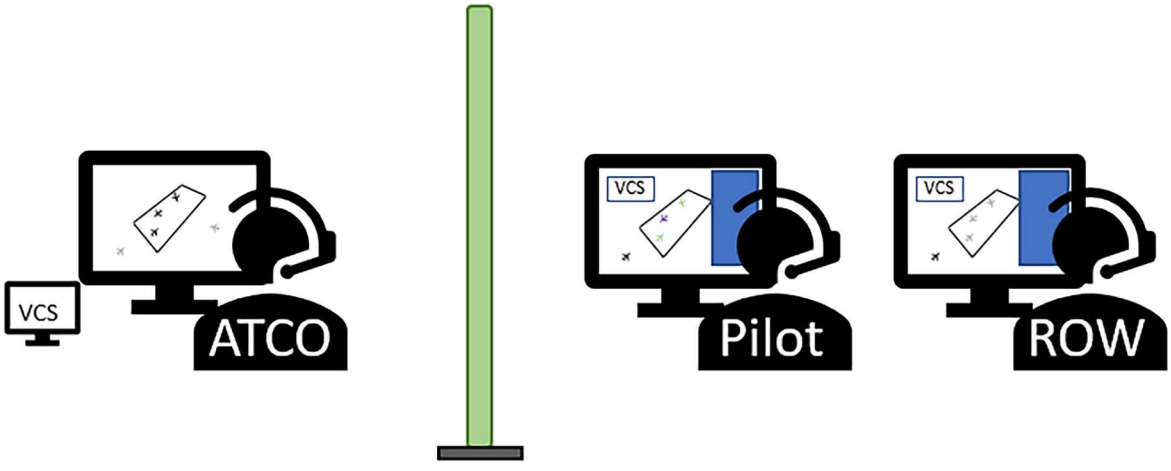

Figure 4. The setup consisted of one ATCO, one simulator pilot and one rest-of-the-world (ROW) position. The simulator pilot *steered* the aircraft controlled by the ATCO, and the ROW position *handled* traffic outside the simulated sector and acts as ATCOs in those sectors. In addition to the main 43″ screen, the ATCO also had a 10″ voice communication system (VCS) touchscreen, while the pilot and the ROW had this integrated into their main screen. The ATCO and the pilot/ROW were situated in the same room but physically separated by a partition wall.

developed. The traffic load and complexity were similar in the two scenarios and based on historical traffic data. Half of the participants started with traffic scenario A and vice versa. One of the scenarios was run with an immediate rotation of the conflict symbol as SVC and the other one with a gradual rotation, and it was altered if the participants started with an immediate or a gradual rotation. Furthermore, it was also ensured that it was not always the same combinations of scenario and rotation that were run in the morning or the afternoon respectively. Table 1 shows the resulting matrix of participants, traffic scenarios, and rotation types.

2.5. Technical SVC setup

A Tobii Glasses 2 eye tracker was used together with an in-house developed software, the SVC system, to allow for high-precision tracking on large (4k 43" 16:9) screens with correlation to on-screen objects. Tobii's recommended default settings for fixation time was used (60 ms). The identification of the conflict symbols was performed by OpenCv template matching in the Narsim video output stream, identifying first the Conflict Window and then the symbols. The area to be looked at was defined as a circle circumscribing the symbol, thus including both rotated and not rotated symbols. Tesseract optical character recognition (OCR) was used to identify specific conflicts by their conflict id. The symbols' x,y screen positions were compared to the eye gaze stream using QR codes in the screen image overlay to correlate the gaze data to the screen, Figure 5. Conflict symbols not looked at for more than 30 s were modified with an overlay on the original image, before being sent to the screen. By using this technical solution, no integration with the simulator was needed.

2.6. Preparations

The limit of 30 s was set based on test sessions prior to the simulation, where different time limits were tested to find a setting that should provide data, yet not trigger rotation of the symbols as soon as the ATCO looked away from the Conflict Window. The procedure of using pretests was chosen to find an optimised setting for the specific environment, which the literature could not provide. There are indications though that motion onset itself can catch attention (Smith and Abrams 2018). The goal of this experiment was to test the solution suggested by Nylin, Lundberg, and Johansson (2020), hence, only 45 degrees rotation was tested. The pretests were performed by the research team, which included ATCO competency, and included both runs with the complete setup during scenario testing as well as smaller tests in a lab setting. The lab setting also included correct hardware with respect to screen size and resolution in the simulator. The ambition was

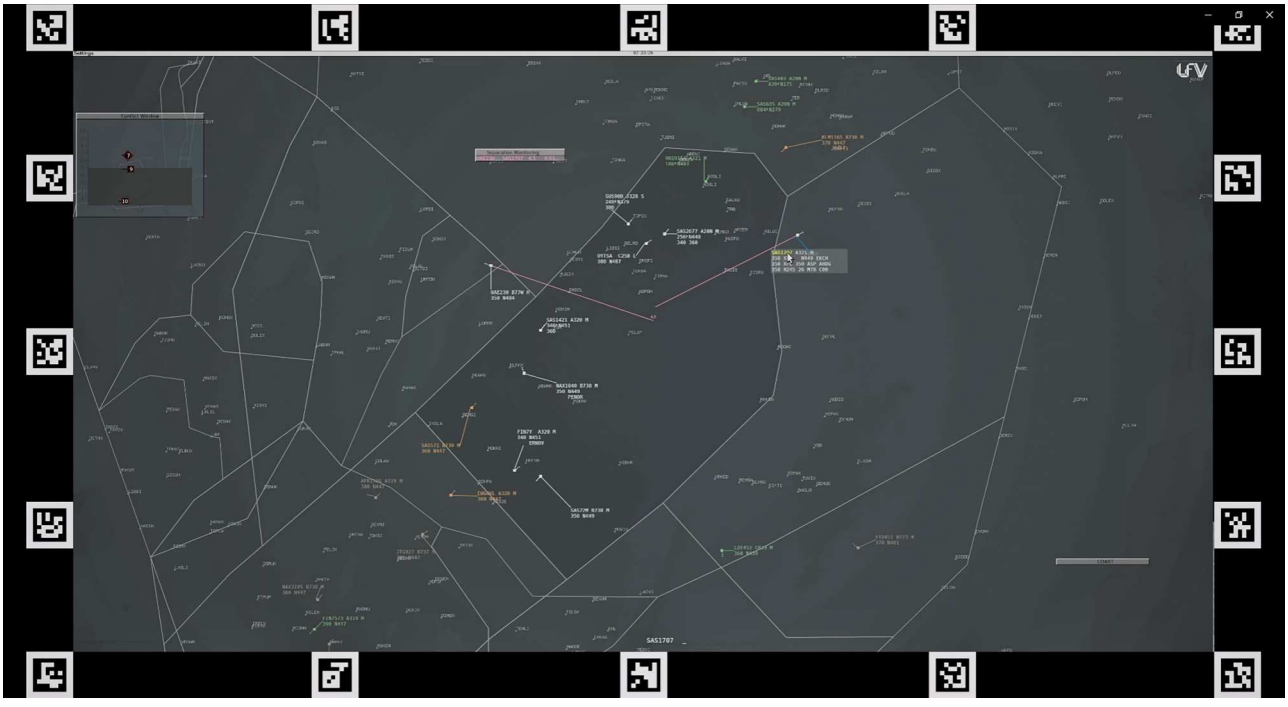

Figure 5. Screenshot from the 43" screen as presented to the ATCOs. The black frame with QR codes is part of the image overlay. The air situation display was sized so that it was not covered by the frame with the QR-codes. The Conflict Window can be seen in the upper left part of the screen.

to get 10–20 data points per simulation run, depending on the individual use of the tool by different ATCOs. The test sessions revealed that using such a short period of time to trigger the SVC often resulted in multiple modified symbols at the same time, which would reduce the power of the SVC as a reminder and make it more difficult to compare different simulation runs. As this was an experiment artefact – in a real implementation, these reminders should not occur as often as in the simulation – a limitation was introduced to allow only one modified symbol at a time.

2.7. Data collection

Prior to the first simulation run, a briefing was held where the purpose of the project and the study was presented. The participants had the possibility to ask questions, were informed about the prerequisites for participating, their rights as participants, and then signed an informed consent. Before commencing the simulation runs, participant background data (gender, age, and working experience) was collected.

During the simulation, data was recorded for measurement and analyses to support the qualitative data from the debriefings, as was metadata for identification of exercise runs. The most important data to be logged was the symbol events; when a symbol was looked at, rotated, and when the rotated symbol was removed. In addition, screen capture and the Glasses front camera recordings were collected. Table 2 provides an overview of the recorded data. Standard Narsim log data about traffic, such as ATCO input, was saved to be available if needed.

The main data source for the analysis was the qualitative data collected using questionnaires and semi-structured debriefings. After each run, the participants rated to what degree they agreed on four statements with respect to the intrusiveness of the SVCs. A ten-step scale was used where 1 meant *Do not agree at all* and 10 meant *Totally agree*. The same questions were used in the first SVC study Nylin, Lundberg, and Johansson (2020). The statements, originally given in Swedish, were:

- The different symbol is intrusive
- The different symbol is unobtrusive
- The change to the different symbol is intrusive
- The change to the different symbol is unobtrusive.

After both simulation runs, the participants rated to what extent the rotation of the conflict symbol corresponded to the statement that the symbol fulfilled the purpose of being an SVC. Both immediate and gradual rotations were rated. The rating was performed by placing a printed paper symbol for the respective rotation variants in one of twelve positions in an array of boxes printed on an A3 paper, where the left-most position meant *Do not agree at all* and the rightmost position meant *Totally agree*, Figure 6. They were not allowed to give the same rating to both rotation types. A similar evaluation was performed in Nylin, Lundberg, and Johansson (2020) to rate the different designs (Figure 2).

The final part of the data collection was a 45-min semi-structured debriefing. The participants were first asked to elaborate on the rating of fit for purpose. Further, they were asked about:

- major pros and cons with the SVC concept,
- if and how sense of urgency with respect to shortest calculated distance and time to shortest calculated distance should affect the SVC,
- if there are other elements in the working environment where SVCs could be appropriate,
- and how the SVC should be implemented for the executive controller (EC) and planner controller (PC) respectively when working pairwise.

The answers from the debriefings were grouped into the above categories by the researcher responsible for the data collection.

Table 2. Data recorded from the SVC system and video recordings.

Recorded data	Comment
Symbol events	Following events were logged: • Looked at • Rotation start • Rotation end • Changed symbol removed by conflict resolved • Changed symbol removed by being looked at
Screen capture	Capture of output from the SVC system, i.e. radar screen plus overlay with modified symbols.
Eye tracking front camera recording	Video stream and sound recorded by the Glasses' front camera.

3. Results

Our results are based on 18 simulation runs, nine with immediate rotation and nine with gradual rotation. The results are presented in three sections. The first two relate to ATCO experience, based on data from debriefings and after run questionnaires respectively, and in the last section, quantitative data from the eye-tracking is presented.

In the following sections, we present the empirical basis for our main results: first, the design seemed to

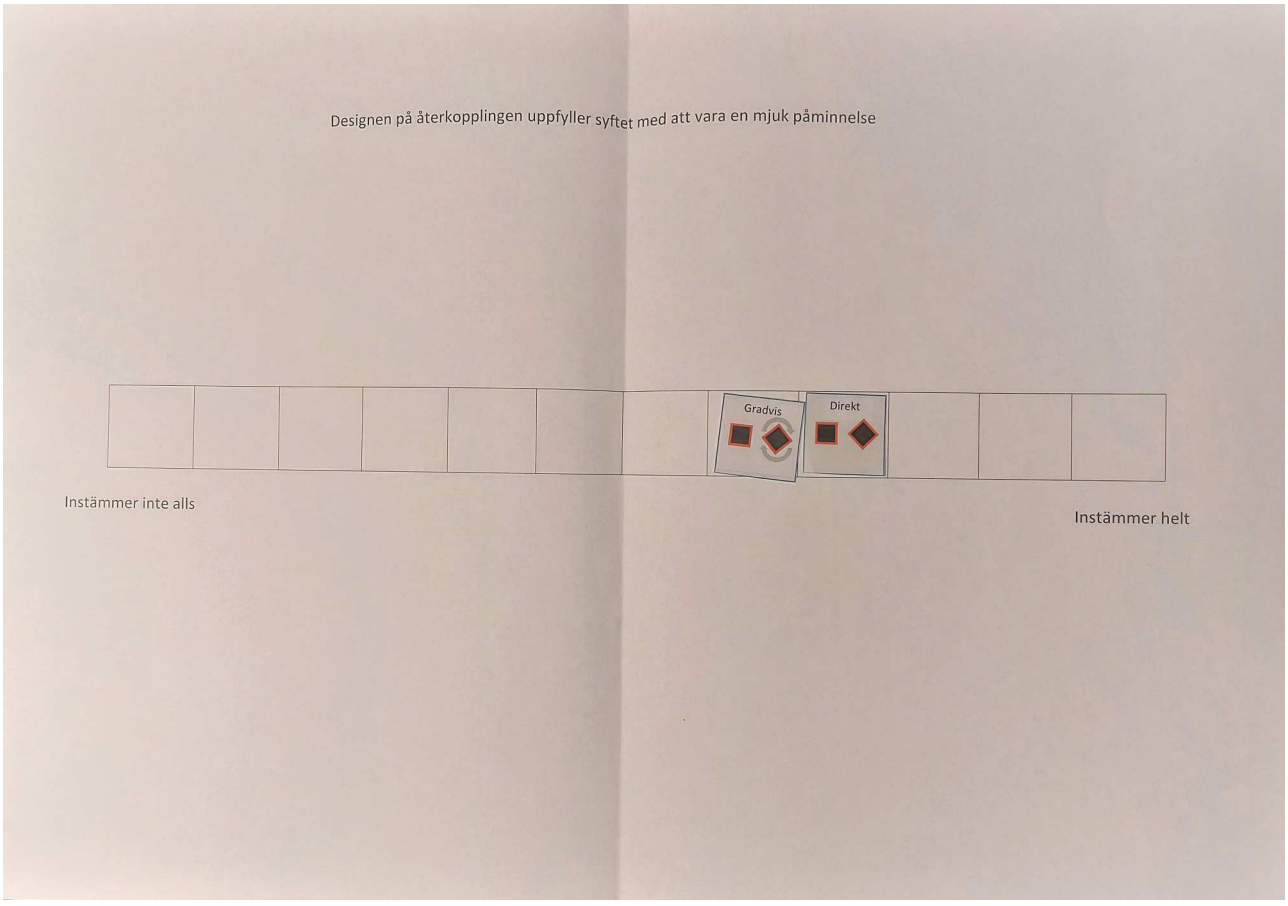

Figure 6. The scale on an A3 size paper used for rating to what extent the designs fulfilled the purpose of being a soft visual cue. Leftmost position: do not agree at all, rightmost position, fully agree. The two tags with symbols represents the gradual and immediate rotation designs. The exercise of ratings the designs also served as a starting point for the semi-structured debriefings, where the participants were asked to elaborate on why they rated the symbols as they did.

fulfil the purpose of being an SVC, and the cue was considered a good reminder. Second, it was also found that changes in minimum calculated distance was considered an important trigger for an SVC. Third, a consistent behaviour of the SVC for both executive and planner ATCO was considered more important than tailoring different solutions for respective role. Fourth, the results do not indicate any differences between immediate and gradual rotation.

Regarding the application case, the participants confirmed that the CARD was a relevant case for SVC. Concerning ecological validity, some participants spontaneously also provided feedback that the traffic scenarios were well balanced with respect to traffic density and complexity.

3.1. ATCO experience: debriefings

In this section, the results from the debriefings are presented. It starts with the participants' rating of fit for purpose for the symbols on a 1–10 scale. This is followed by more detailed feedback from the debriefing interviews grouped thematically by the interview protocol structure: Pros and Cons, Sense of Urgency, Relevance for Executive and Planner Controller, and Other Areas for SVC and General Feedback.

3.1.1. Fit for purpose

Table 3 shows the subjective rating of the extent to which the change of symbol fulfilled the purpose of being a soft visual cue. Most scores provided ratings between 7 and 12 (maximum 12) with two exceptions. In both of these cases, the reason for the low rating was that the SVC was considered too soft, i.e. did not stand out enough. The size of the Conflict Window, including the symbols, was mentioned as one

Table 3. Results, rating of fit for purpose.

Statement	Gradual (1–12)	Immediate (1–12)
The different symbol fulfils the purpose of being a soft visual cue.	9.6	8.4

contributing factor as it was smaller than they were used to in the operational system. In one of those cases, the immediate rotation got a very low rating which counts for almost all the difference in the mean results for the two designs (lowered the mean by 1.0). However, there were generally no strong opinions with respect to the type of rotation.

3.1.2. Pros and cons

The most positive aspects of the SVC concept reported during the debriefings were that it created awareness about the CARD, not only by reminding of potentially missed conflicts, and that the reminder itself was good – the risk of missing information in the CARD is well known.

Two of the participants reported that even if the concept was good, they experienced the cues to be *too* soft, end even not seen when looking at the conflict window. The latter though was only reported for one run, and there was nothing in the log files that indicated any difference compared to other runs – the symbols had been looked at, but not consciously observed as rotated. Though not the case in the simulation, it was identified as a risk that reminders of conflicts that are not forgotten but not looked at – conflicts may be identified by other means than using the CARD – could be annoying. One suggestion to mitigate this was to exclude reminders about conflicts that have been added to the separation monitoring tool. In that tool, pairs of aircraft in conflict are manually added to a list of conflicts and visualised in the air situation display by prediction lines in distinct colours for each pair.

3.1.3. Sense of urgency

Most of the participants considered that no reminders at all would be needed earlier than 10–15 min before the shortest calculated distance between the aircraft. This time span can probably be attributed to domain specific aspects, such as certainty in predictions, speed of aircraft, working procedures and sector sizes. At a minimum, it was considered that the reminder must appear five minutes before the occurrence of shortest calculated distance for the ATCO to discover the SVC and take appropriate action. It was less conclusive whether the shortest calculated distance should be a parameter for the triggering of an SVC. Some argued that as long as the conflict is present in the Conflict Window, it is relevant, while others considered it shall only be triggered if the distance is close to the separation minima (5 NM). Rather, *changes* in shortest distance were considered more important than the distance itself. This also resembles a functionally already in use today in the operational system: The ATCOs can mark a conflict as taken care of by clicking on it, which turns the symbol grey. If the distance changes, the symbol resumes its original colour. However, the symbol may still be missed, since the symbols change position when there are changes in calculated time or distance, and the functionality is not used by all ATCOs. The simulator did not include all of this this functionality, only the possibility to grey out the symbols.

3.1.4. Relevance for executive and planner controller

Some participants stated that it would be more important for the Executive Controller (EC) to have the SVCs since the time to shortest distance is lower than for the Planner Controller (PC). Further, if the PC misses a conflict in the CARD, it might still be detected by the EC. Other participants stated that the SVC would be more important for PC. However, none of these opinions was very strong. Since the ATCOs alter between the EC and PC role, most participants considered a consistent behaviour for the SVCs to be more important than to match the respective roles perfectly.

3.1.5. Other areas for SVC and general feedback

There were only a few specific suggestions for other areas in the ATM system where SVCs were considered useful if implemented. One was a list for coordination of traffic passing through segregated areas. Another list called Traffic Management List was also mentioned where updates of times were reported to be relatively easy to miss. Reminders in form of SVC in the transfer of control process between sectors was another area mentioned, both as a reminder if an aircraft calls up on the frequency and does not receive an answer, or if transfer of an aircraft to next sector has been missed.

A general observation from the feedback provided during the debriefings was that the use of the CARD differs between ATCOs. Some ATCOs emphasised that they use the tool a lot, while others said that they use it less frequently. Further, the use of the tool was reported to go down when the workload goes up. In those cases, the focus is concentrated on the radar screen, and the situation right here and now and conflicts in the CARD will not be looked at all. There is a possibility to have conflicts indicated as a red dot in the aircraft label, that is, if two aircraft are in conflict, they will both have a red dot in the label in addition to the CARD representation. It was suggested that SVCs could be used in the label indicator as well at the same time as the symbol in the CARD and thereby notify the ATCO if a conflict is overlooked.

Table 4. Results, rating of intrusiveness.

Statement	Total (1–10)	Gradual (1–10)	Immediate (1–10)
The different symbol is intrusive	1.94	1.89	2.00
The different symbol is unobtrusive	8.94	8.78	9.11
The change to the different symbol is intrusive	2.11	2.00	2.22
The change to the different symbol is unobtrusive	8.72	8.56	8.89

3.2. ATCO experience: post run rating of intrusiveness

The assessment of intrusiveness filled in after each simulation run showed that neither the symbol itself nor the rotation were considered intrusive. The total average rating for the statements that the symbol and the change was intrusive was 1.9 and 2.1 respectively at the ten-degree scale (a low number means do not agree with statement), while the statements about unobtrusiveness were rated at an average of 8.9 and 8.7 respectively. The numbers are presented in Table 4, where they are also divided into gradual and immediate rotation. The ratings were very consistent. There was only one outlier in the material where the changed symbol was considered relatively intrusive. However, that was later explained during the debriefing as being positive – it was interpreted such that it was a good reminder. It was still not considered to draw attention from other work.

3.3. Recorded times for symbol rotation and looked at

The logging from the system shows when the conflict symbols were rotated and when the ATCOs looked at the symbols. It provides a complement to the results from the debriefing with respect to potential differences between gradual or immediate rotation and if the cue draws attention to it.

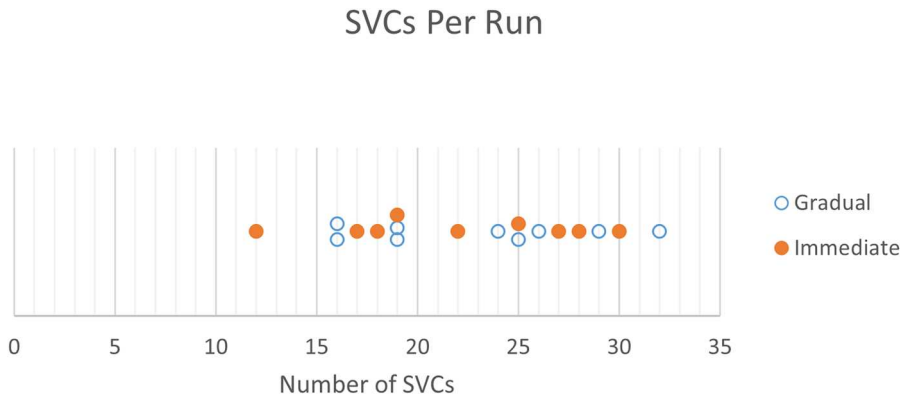

Figure 7. The total number of SVCs initiated by the SVC system per run. The number differed depending on how the traffic scenarios evolved, i.e. how and when conflicts were solved, and how the ATCOs used the Conflict Window. Note that the figure only illustrates the numbers and that there is no *y*-axis. The vertical displacement of the dots is because there were multiple instances with the same number.

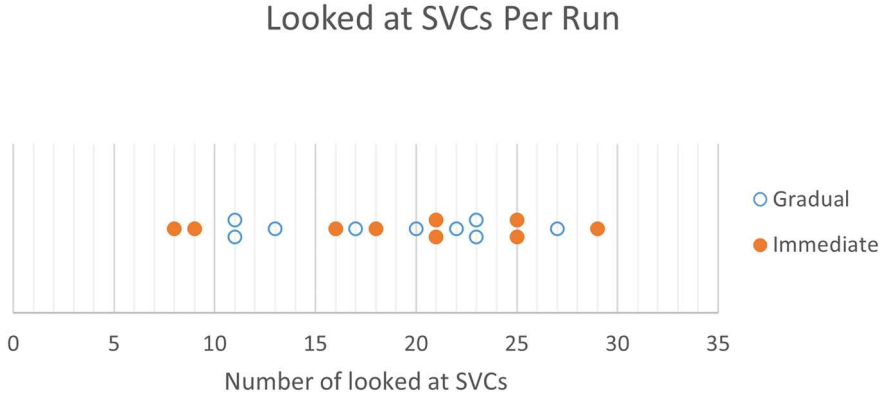

Figure 8. The number of SVCs per run that were looked at by the ATCO. Note that the figure only illustrates the numbers and that there is no *y*-axis. The vertical displacement of the dots is because there were multiple instances with the same number.

Table 5. Results from logged data with respect to detection time.

	Gradual	Immediate
Number of symbols looked at	167	172
Mean changes per run	18.6	19.1
Mean time to looked at (s)	35.04	35.41
Median time to looked at (s)	24.6 (IQR 8.6–48.3)	22.2 (IQR 9.0–39.6)

During the 18 simulation runs, a total of 404 SVCs were issued by the SVC system. Of these, 206 were gradual rotations and 198 were immediate rotations. The number of SVC issued per run differed depending on the actions taken by the ATCOs and how much the ATCOs used the Conflict Window. It ranged from 12

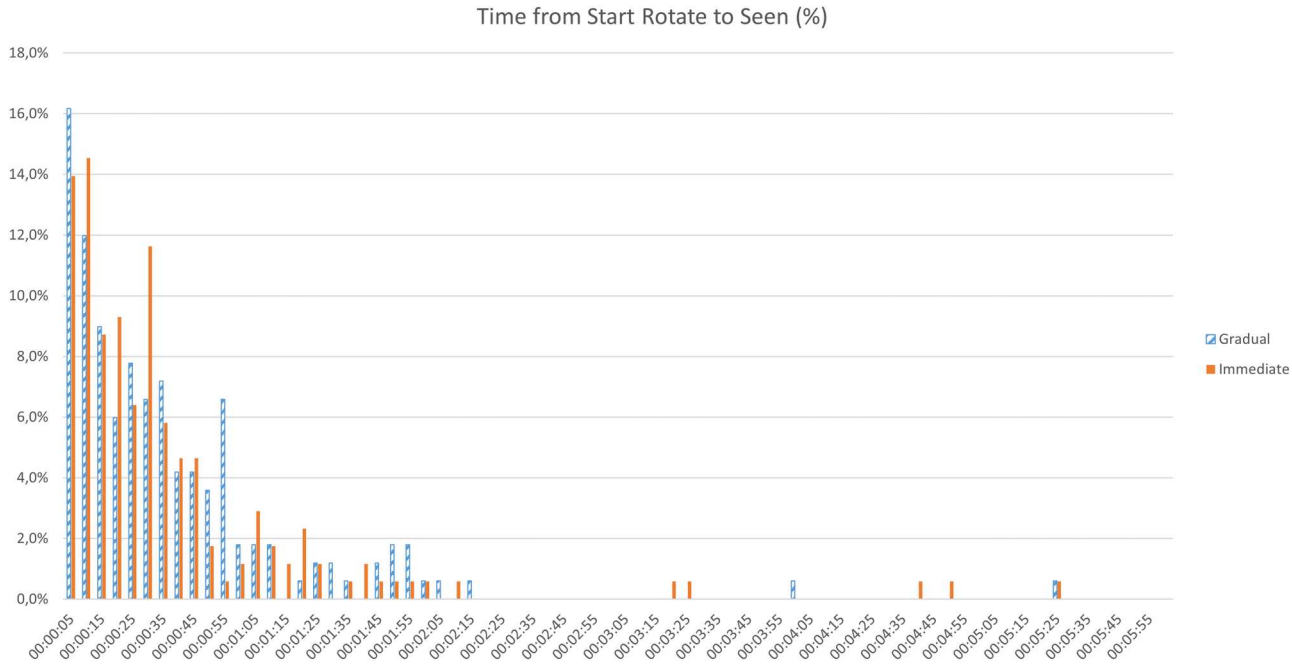

Figure 9. Distribution of times from rotation start to seen by ATCO for gradual rotation (blue bars) and immediate rotation (orange bars). The times are grouped into 5-s intervals.

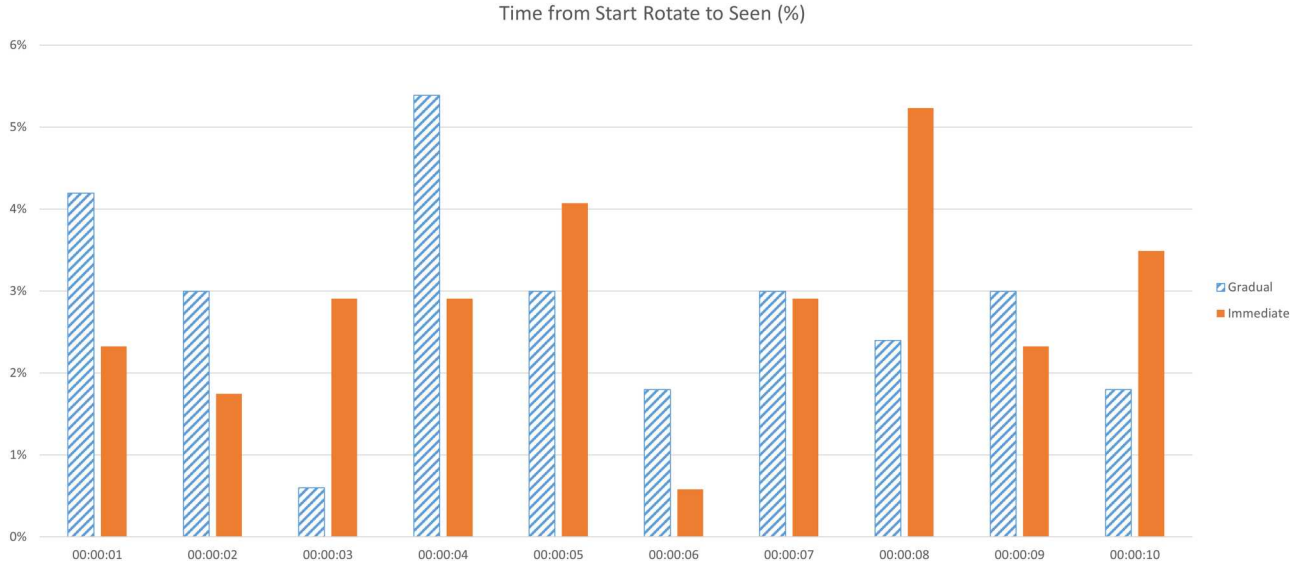

Figure 10. A zoomed in view of the distribution of times (the first 10 s) from rotation start until symbol looked at, where the times are grouped per second. These constitute 28.1% (gradual) and 28.5% (immediate) of the total number of start of rotation to looked at occasions. 16.2% and 14.0%, gradual and immediate rotations respectively, are within 5 s.

to 32 SVC per scenario (mean 22.4, median 23), see Figure 7 for the distribution of SVC per scenario.

Of the 404 SVCs initiated, 339 were looked at by an ATCO and 167 (of 206 issued) of those were gradual rotations, and 172 (of 198 issued) were immediate rotations. Figure 8 shows how many SVCs that were looked at per simulation run.

Mean number of SVC looked at per run was 18.6 (gradual) and 19.1 (immediate). On average, it took 35.04 s (Std. dev.40.66, median 24.00 s), from rotation start until the ATCO looked at the symbol for the gradual rotation. For the immediate rotation, the average was 35.41 s (Std. dev. 47.50, median 22.50 s). See Table 5 for a summary. Looking at the results at participant level, the average time to looked at differs more, on average 38.44 s for gradual rotation and 46.35 for immediate rotation (likely due to variances of number of rotations between runs). However, a paired *t*-test showed no significant differences between gradual and immediate rotation, $p = .53$ with a small effect size, Cohen's $d_z = 0.22$.

In Figure 9, the distribution of time from rotation start until the symbol was looked at is showed with times grouped in 5-s intervals. Figure 10 shows the distribution of times with a higher resolution of 1 s, i.e. the two first intervals in Figure 9. The times within 10 s constituted 28.1% of the total number of rotation start to symbol seen occasions for gradual rotation and 28.5% for the immediate rotation. For some intervals, there are an overweight of gradual rotations seen compared to immediate ones and vice versa. No clear differences, such as if there should be an overweight of one of them for the lower intervals, can be distinguished. On 27 occasions (16.0%) of the gradual rotation scenarios (on average 3.0 times per run), the symbol was looked at *during* the rotation of the symbol.

4. Discussion

One of the most important results was that there were no reports of the SVC attracting attention from something else or being perceived as intrusive. The latter was with one exception, but the appending explanation was that reporting it as intrusive was to be interpreted as something positive – it stood out sufficiently and was not considered disturbing at all. Approximately 15% (16.2% for gradual and 14.2% for immediate rotation) of the time from start of rotation of the conflict symbol until it was looked at was within 5 s or less, that is, within which time the rotation matters. In only 4.2% (gradual) and 2.3% (immediate) of the cases, the rotation was discovered within a second. This supports what was reported by the participants – the rotation did not actively draw attention to the symbols.

4.1. Softness of the cue

The feedback from the participants with respect to the softness of the cue differed. It ranged from the opinion that it was too soft and almost not distinguishable to that it stood out very clearly, perhaps more than the purpose of being a soft cue, even if it was appreciated. However, those who thought it was too soft also said that it might be an effect of the high screen resolution, which made the on-screen objects slightly smaller than in the operational system, and that making everything bigger would make it better. This range in opinions about the softness of the SVC shows that there is probably not one perfect solution that will fit all perfectly. One explanation could, for example, be differences in expectations and that the individual interpretations of what an SVC should be, even if all were given the same introduction. Further, it could be affected by individual differences in perception and visual acuity. It could also be as simple as different individual preferences. From a more general perspective, this raises the question of whether the different opinions on the softness would differ in the same way between individuals in other domains.

However, even though the opinions of the cue's softness differed, the results from the rating of fit for purpose (9.6 and 8.4 on a 12 grade scale, Table 3) shows that it can be considered to have a softness that was relevant for the scenario tested.

When analysing the logs, two related questions worth mentioning emerged, though not explicitly addressed questions in the study – missed SVC and if the SVC always were the first to be seen in the case of multiple symbols present.

It was noted that for most runs, there were a few SVCs (on average 3.8 for gradual and 2.9 for immediate) that were never seen before the conflict was removed from the Conflict Window (conflict solved or aircraft have passed each other). A closer look at those revealed that the majority of these could be contributed to two main reasons: (1) The symbol was only displayed for a short period of time, often just a few seconds, and (2) The ATCO did not look at the Conflict Window at all for a longer period, hence did not see *any* conflict, SVC or not. On five occasions the ATCO did look at another conflict and yet not the SVC. However, in four of these cases, the cued conflict had been looked at earlier. Although not possible to know, it could indicate that the conflicts were considered to be

under control, and the focus was on other conflicts. However, a more controlled experiment is needed to establish how common this is and why it happens. This should probably also address if individualisation of salience or time limits are needed to achieve best possible SVC effect. The same dynamics as described above may also explain the spread in detection time – the SVC is not recognised until attention is on the conflict window. Why the conflict window is looked at or not may have many causes such as traffic situation or preferred way of working. Accurate softness may also be affected by multiple concurrent SVCs. This was not addressed in this study but should be taken into consideration in future studies.

Likewise, there were a few occasions per run (average 2.1 for gradual and 2.7 for immediate) where other conflicts were looked at before the one cued with an SVC. However, it is impossible to draw any conclusions from that due to the dynamic nature of the simulation (see also Section 4.4). It could, for example, be that the ATCO is actively working with a certain conflict (not the cued one), thus mainly focusing on that. Another influencing factor is the position of the Conflict Window and the symbols' position in the window. If a non-cued symbol is closest to the part of the Conflict Window where the gaze enters the window, it may be the first one looked at even if there is a symbol that is cued in the other end of the window.

4.2. When to remind

The discussion of softness also relates to temporal aspects. When shall the operator be reminded, and what time is left to react on the cue and verify the effect? In ATC, the controllers work on relatively short time horizons, and actions such as a turn, are implemented by the aircraft and can be observed by the ATCO within seconds. In other domains, this may be different. For example, in Vessel Traffic Service (VTS), it might take several minutes before a ship is initiating a turn until the turn can be observed by the VTS operator. Hence, such domain specific prerequisites must be considered if designing SVCs for other domains, even if the domains may look similar in other aspects. This also relates to gaze scan patterns. If many areas of interests are to be scanned, and if scanning is taking place with longer intervals, the SVC must be issued earlier to achieve the intended effect.

4.3. Extended use of SVC

There were few examples given by the ATCOs of other elements in the user interface where SVC could be used. To some extent, this may be attributed to the difficulties of providing such suggestions during a debriefing session, not having the real system in front of them. It may also be because a lot of information in the interface is represented in text format, thus leaving fewer options for SVC designs in the form of changes in geometrical properties like the one used here. A few ideas for the implementation of the concept in different lists were mentioned, but it remains to be solved how an SVC for text in a list could be designed. For example, colours were ruled out already in Nylin, Lundberg, and Johansson (2020) due to the extensive use of colours for other purposes. Reminders of transfer of control, which was one suggestion, might be easier from an SVC design perspective. However, there are technical challenges if it shall include information about what is communicated as long as the communication is primarily performed over VHF radio which is a separate, analogue system. That would probably require real-time speech recognition and analysis. This could be overcome with extended use of data link communication.

The symbols used for SVCs in this study are in themselves only squares in a scatter plot representation. Hence, the same type of SVC design should be applicable in other visualisations built upon similar kinds of graphical elements, given that it can be assumed that the area where they are presented is systematically looked at in a visual scan patterns. It must be kept in mind though that the specific design is dependent on the overall design of the interface – if colours are sparsely used for other purposes, it might be a good design candidate in another system even though it was not the case here. Drawing far reaching conclusions about general SVC properties in other contexts shall be made with caution since it is likely very context dependent. This would require complementary studies of the concept, some suggestions are presented in Future Work Section 5.1.

4.4. Limitations of the study and reflections on the simulations

It was required for the study to get the experiences of the concept from operators with highly trained visual scan behaviour, in realistic environments. In this case, ATCOs. The best option from the perspective of realism would have been a live environment, however, for safety and security reasons, that was not possible. The best remaining option was to use a real-time human-in-the-loop simulator that closely resembles the visual operating environment, and with realistic traffic and tasks. Some comments we received nevertheless referred

to how the participants were affected by the fact that the environment in the simulator was not identical to that of the real system. Some just accepted it and started working, while others said that it required some effort to handle the differences, such as how to use the vector distance measuring tool or the sensitivity and speed of the mouse cursor. However, no other disturbances were present during the simulation, which made it less demanding from that perspective. The traffic scenarios were reported to be well balanced and realistic for single ATCO operations of the sector, which should have contributed to a realistic environment.

Performing the study in a realistic environment provides a higher ecological validity, but it also means less control – the traffic scenarios start the same but develops depending on the actions taken, just like in reality. Hence, the number of conflicts in each scenario, when and where the conflicts appeared, and where in the Conflict Window they were presented differed. This means that it is harder to get comparable quantitative data. It was a trade-off made since the ATCO experience was most important to catch to evaluate whether the SVC worked as a concept. Future studies could complement this study with more controlled experiments, for example, to research efficiency of different SVC designs, including different rotation speeds, or effects of where the window is located. This would also make it possible to explore the effect of traffic scenarios with different levels of complexity. It shall be noted though that controlling complexity of the traffic scenarios is very difficult due to the dynamic nature of the processes. Too rigid control means less ecological validity and may result in a much narrower scope, which would not capture the richness of operational aspects gathered here such as that the ATCOs sometimes did not even look at the MTCD window.

The ATM system that the ATCOs in this study use operationally in their daily work is used in at least five countries, and most ATM systems have similar functionalities. From previous experience, we know that ATCOs work in similar ways. Therefore, it is reasonable to believe that the same design should work in other area control ATM systems in other locations. However, that cannot be proven here. Operators in other domains with similar control room environments may have different scan patterns and other visual contexts. Hence, even if the concept is generic, the SVC designs must be adopted to the domain specific contexts.

We are aware that the number of ATCOs involved limited the possibilities to perform meaningful, quantitative analyses. This is typical for this kind of studies with active ATCOs that are recruited from operational duty, and since highly trained visual scanning behaviour was a prerequisite, using, for example, ATCO students was not an option in this case. Nevertheless, the quantitative data provided a valuable support to the qualitative analyses, for example to the feedback from participants that attention was not directly attracted by the symbol change. It shall also be kept in mind that the participants represent a small professional community that is very homogeneous with respect to their expertise, having had identical education and training, and who are working in a strictly regulated environment. The total number of ATCOs at LFV are approximately 600 LFV (2025), which include ATCOs from 16 ATC towers that do not use the system. Hence, even if the number of participants may seem to be in the lower span from a general perspective, it can be considered adequately representative in this context.

5. Summary and conclusion

A series of real-time human-in-the-loop simulations were performed to test the implementation of the Soft Visual Cues (SVC) concept in a conflict visualisation tool for Air Traffic Controllers (ATCO). The SVC is a form of attention guidance, first presented in Nylin, Lundberg, and Johansson (2020), developed to provide visual attention support without actively attracting attention, as with alarms or attention guidance, to a certain area of interest. The overarching design idea was that the SVC shall be noticed when looked at, but not otherwise.

The implemented design consisted of a rotation of the symbol (a square) that represents a conflict in the Narsim simulator's Conflict Window tool, a tool similar to the Conflict and Risk Display (CARD) used in the operational Air Traffic Management (ATM) system. The position of the symbol in the scatter plot that constitutes the Conflict Window depicts the shortest calculated distance between two aircraft in conflict and how much time there is left until that occurs. Eye-tracking equipment, Tobii Glasses 2, together with a real-time image analysis and modification system was used to identify if a conflict had not been looked at for 30 s. When that time had passed, the square was rotated by modifying the image produced by the simulator before it was presented on the screen. The time for rotation and the time when the ATCO noticed the modified symbol were logged and analysed. In addition, the participants provided feedback through questionnaires and semi-structured debriefings on their experience of the SVCs.

The main purpose of the study was to explore the ATCOs' experience of the SVC in a realistic environment, and to what extent they considered the

implemented design to fulfil the purpose of being an SVC. Data was collected in semi-structured debriefing sessions and post-run questionnaires about intrusiveness, complemented by eye gaze data to indicate if attention was actively drawn to the SVCs. In addition, it was explored if there was a difference between using a gradual or immediate rotation of the conflict symbol and if the SVC was thought to be equally important for the different ATCO roles, Executive Controller (EC) and Planner Controller (PC).

Overall, the results indicated that the implemented design of the SVC concept met the expectation of the SVC concept – it was considered a good reminder that the participants noticed, but it did not seem to actively draw attention to it. It was found that:

- SVCs were considered a usable concept for reminding about missed information that is not alarmingly urgent.
- The proposed SVC design did not seem to attract attention other than when looked at and was not considered intrusive.
- The results did not indicate any clear difference between gradual or immediate rotation.
- Knowledge of the visual environment and domain properties is important to create a good SVC design.
- For the specific use of SVC in the CARD, it was found that:
  1 SVCs in the CARD are not relevant earlier than 10 to 15 min before the critical moment, in this case shortest distance between two aircraft.
  2 SVCs were considered usable both for Executive Controllers (EC) and Planner Controllers (PC). Despite the difference in time horizon on which the EC and PC work, it was considered more important to have a unified behaviour for when an SVC is triggered than to tailor it for the respective role.

5.1. Future work

Our implementation and design of the SVC concept was found to function as intended, as a gentle reminder, to the operational experts in the work environment in which it was implemented. It is likely that the concept would be beneficial in other domains that comprise similar control room environments for real-time control of external processes. For instance, based on our results, it seems promising to test the concept with designs for operators in domains such as Vessel Traffic Service (VTS) and Train Traffic Management (TTM) (which were part of the Nylin, Lundberg, and Johansson 2020 study). Such studies can shed light on the usefulness of the SVC concept in other domains comprising operators with highly trained visual scan behaviour, but with other tasks and variations in the pace of control. It would also be relevant to test the concept for ATM in other countries, both those who use the same system and in other ATM systems. These tests could also include studies on how many SVC that should realistically be triggered at the same time, how often, and detection time of these. However, this possess challenges from a practical perspective as it would require a longitudinal study in an operational environment.

Future work could also include exploring other types of SVCs to see if the type of cue is related to specific elements in, or properties of, the environment in which it is implemented. A specific property to look at could be the temporal aspects in different domains, for example, the process pace in relation to when to issue the SVC, and if and when to switch to more salient attention support. It is also suggested to perform quantitative studies to assess, for example, efficiency of different SVC implementations.

Using eye-tracking glasses can, as happened once here, be considered uncomfortable and disturbing. Hence, research on other types of eye-tracker types, or other sensors providing similar information, is encouraged. Especially, this can be an issue for operational, and thus long-term, operational use.

This study focused on one implementation of SVCs in one ATM system's tool; the CARD. Future steps in this domain could include the use of SVCs in other parts of the system that have screen object contexts consisting of other sizes, shapes, and visual arrangements than the CARD. It would also be possible to explore SVC implementations in the CARD that is able to detect if a conflict is noticed by the operator in other ways than by looking at the CARD symbol. Based on feedback from the debriefings, we also suggest more complex studies that include interaction with other tools relating to the same conflicts, such as the conflict monitoring tool for monitoring specific conflicts and the label conflict indication in the SVC concept. This would be of importance to reduce the risk of missed SVCs if the CARD is disregarded in high workload situations. It would also be of interest to investigate restricting parameters, for instance, shortest calculated distance between the aircraft and when it is calculated to appear.

Finally, adding more intelligence to the SVC design could expand the possibilities within the concept and increase the possible gains by making it more flexible. This could, for example, include studies of personalisation by learning abilities in the attention support system to match individual operators perceptional abilities or preferences.

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Author contributions

CRediT: **Magnus Nylin:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing; **Gustaf Söderholm:** Data curation, Formal analysis, Investigation, Software, Validation, Writing – original draft, Writing – review & editing; **Jonas Lundberg:** Funding acquisition, Supervision, Writing – original draft, Writing – review & editing; **Magnus Bång:** Funding acquisition, Software, Supervision, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Ethical approval

An application for ethical approval was submitted to the Swedish Ethical Review Authority in a similar project using eye-tracking to retrieve gaze data from air traffic controllers (Nylin et al. 2022). The verdict was that no ethical approval was required for this type of study. Based on that verdict, it was concluded that no ethical approval was needed.

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