Attention Support with Soft Visual Cues in Control Room Environments

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***Abstract*—In visually demanding environments like working positions in air traffic control, there is a risk of missing important information. Attention support might help to reduce this, but there is a risk that it introduces new issues in the form of distractions or increased visual load. The work presented in this paper explores the concept of *Soft Visual Cues*, with the aim to make the operator aware of missing information, but doing it discreetly enough only to be noticed when the operator is scanning the area where the information is present, thereby complementing the concepts of attention guidance, alarms, and subtle gaze direction. The qualitative evaluation performed aimed primarily at catching the operators' (air traffic controllers) first impressions. Focus was on air traffic control, but was complemented with vessel traffic service and train control environments and operators. The results from air traffic control showed a preference for symbol property changes related to geometry rather than for colour or opacity changes as soft visual cues. The comparison to the other domains highlighted the contextual dependence, visual context and process context, of the concept.**

***Index Terms*—Soft visual cues, attention support, adaptive automation, interactive visualization, air traffic control, train control, vessel traffic service.**

I. Introduction and Background

In control room environments as in the domains of air traffic control (ATC), train control, and vessel traffic service (VTS), the operators' handle large amounts of visual information, as illustrated in Fig. 1. There are different symbols, tools, menu systems, etc. with a large set of properties and colours, all of which have their own specific meaning. These environments are built for, and used by, highly specialised experts, i.e. air traffic controllers (ATCOs), train dispatchers, and VTS operators. The human machine interfaces must provide enough information to the operators, yet without overloading them. However, even if well designed, there is still a risk that important information is missed, not at least when the workload is at the upper or lower end of the operator's capacity. The above mentioned domains share similar control problems, though in this study focus was on the ATC domain. Different concepts of attention support have been developed to tackle the problem, but they do not cover all aspects. By a qualitative approach including subject matter experts, this study explored a way of closing such a gap. The subject matter experts work on a daily basis in these environments and possess unique and profound knowledge about the operational processes and visual environments, enabling them to provide feedback not possible to receive in a traditional perception study with non-experts.

Fig. 1. Air traffic controllers at an Air Traffic Control Centre (ATCC). The image shows two controller working positions with the air situation display (basically a synthetic radar screen) at the central, main screen which is flanked by smaller screens comprising other tools and information displays. Just below and left of the main screen there is a voice communications system touch screen. Press image from www.lfv.se.

A. Air Traffic Control

The overarching goal of ATC is to maintain safety and efficiency in air traffic. ATCOs are working in towers at the airports and in large control centers. The tower controllers deal mainly with air traffic at and in the close vicinity of the airports while the controllers at the ATC centers are controlling en-route traffic and traffic approaching and departing from the airports. The en-route controllers are working with surveillance data (radar etc) as their main tool to control the traffic. To assist the controllers, there is an array of tools that help them to plan, search for conflicts, optimize sequences, and so on - tools of which most are digital and integrated in the air traffic management (ATM) system.

B. Staying in Control

In an information rich environment, missing important information is a real risk [18]. Incident reports show that information can be missed even though presented in the expected manner which has also been shown in simulator studies [12]. In other cases, information may have been seen

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but then forgotten and the planned actions with them [17], or a seemingly salient change can be missed [20]. In many cases there are built in safety nets to avoid incidents developing into accidents, but they are activated late. Once there, with the alarm ringing and blinking, the solutions available may be fewer, and the time to implement them quite limited. That is a condition which reduces the possibility to stay in control and it may take time to work oneself back to a desired situation again [6]. Hence, there are good reasons for finding solutions that can help the operators not getting there in the first place. Techniques such as eye tracking or identifying (the lack of) system interaction can be used to identify if certain information is likely to have been missed. If the system has this knowledge, the question is what to do with it to help the operator in the best way?

II. Soft Visual Cues

One possible answer to that question is the concept of soft visual cues (SVC), introduced in this study. The basic idea is to make the operator aware of missed information when visually scanning a certain area, but to do so in way subtle enough not to draw the attention to it if the attention is currently somewhere else.

Theoretically, the notion of cues in operator environments relates to the notion of Situation Awareness (SA). A cue can alter SA at different levels of impact (frames, implications, objects). Cuing of frames have the highest impact, cuing the operator that a new situation (or significant change) is at hand, while cueing of implications fill in the frame toward details and expected developments in the situations [11]. At the lowest impact level, operators must interpret cues of object status change in terms of implications and frames to gain significance, perhaps in combination with other status changes. This has major design implications on the design of cue strength. Cue strength relate to what is actually sampled, which can be understood in terms of the SEEV (salience, effort, unexpectedness and value) model [7]. Salience and sampling effort are the aspects that can be changed most easily by the designer. These aspects relate strongly to the surrounding visual environment. However, design of cuing must also take into account the unexpectedness of change of the cue, as well as the value of sampling it. These two aspects relate to the control process. Relating to SA, cues pertaining to framing may have the highest value, but also require that the system has the ability to recognize situations or to generate new frames. Situation dynamics relate to the speed of change, which affect attention per see. A too low level of dynamics may contribute to inattention, and a too high level may contribute to information overload. Thus, cues must be evaluated in both a visual context and in a process control work context.

Visual AG has been studied as one way to make an operator aware of missed information [13]–[15] and how visual attention is drawn to outstanding objects is well researched, where different differences attracts our attention more or less easy [19]. However, drawing the attention to something important,

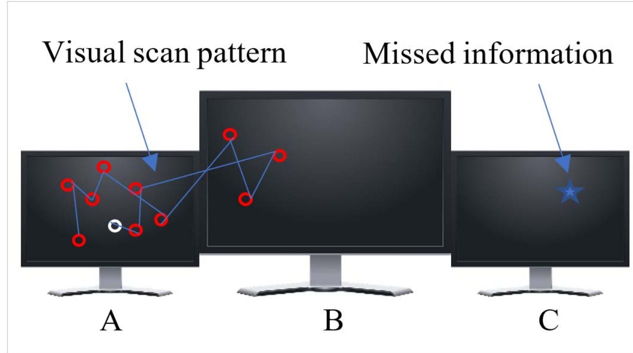

Fig. 2. A generic description of the SVC concept. The missed information on screen C shall not catch the attention of the operator – it has been missed but it is not urgent.

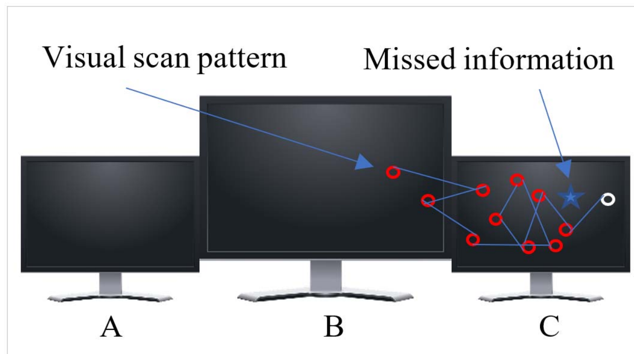

Fig. 3. The scan pattern is now concentrated on screen C, and the SVC given shall now catch the attention of the operator.

but not critical, may interrupt an ongoing process which is even more important or urgent [16]. It may also disturb regular patterns of visual scanning for information and intervene with the operator's intentions, intentions of which the system does not know much. It is quite possible that the operator has intentionally neglected the information as being less prioritised and have put it on queue to be taken care of later - the system simply cannot know. This is why SVC differs from what is usually meant with with AG, or even attention control, which is trying to catch the operator's attention right now, e.g. by making use of the human capability to perceive movements in our peripheral view, something humans are generally good at [3], [9].

Fig. 2 and 3 illustrate how the SVC principle is intended to work in a multi-screen environment. Information on one screen (C) has been missed, but it is not until the operator starts to scan screen C that they become aware of the missed information. As long as the focus is on the other screens (A and B), the SVC shall not draw the attention from them.

The main purpose of the study was to explore how feedback can be given to the operator in a way that fulfils the purpose of SVCs. Or more specifically, if different possible designs of SVCs were considered adequate by operators in the researched domains, focusing on ATC. These operators were highly trained and skilled subject matter experts working in very specific environments, hence it was considered very valuable to get their views on the concept as it may be very different from those of non-experts. It was assumed that the knowledge about the missed information was already in the system.

III. Related Work

There are studies of AG in similar environments (e.g. [8], [13]–[15]). In the most recent of these [14], Ohneiser, Gürlück, and Jauer performed a fairly large scale and hi fidelity human-in-the-loop real time ATC simulation with AG for conflicts and hand over misses using eye tracking. It also incorporated different escalation levels depending on importance. AG was provided in the main, air situation display. The concept of subtle gaze direction (SGD) was introduced by Bailey et al. [2] and elaborated on by others, (e.g. [4], [5], [10]). Lu, Duh, and Feiner [10] worked on photos in augmented reality visualizations and used contrast manipulation as the subtle cueing. Blurring of image parts not intended to be focused on was explored by Hata, Koike, and Sato [5]. Grogorick, Stengel, and Eisemann extended the SGD concept to immersive virtual reality environments [4].

The related work represents two different perspectives of attention support, AG and SGD. To that can be added alarms, which are designed to trigger immediate response. The concept of SVC constitutes a fourth concept or perspective to attention support (Table I). These share the feature of supporting attention but in different ways. The subtlety in SGD was intended to be unnoticed by the user while the SVC is intended to be a gentle but still noticeable reminder. Also, even if the guiding features in SGD, e.g. modulation of luminance in an image, is subtle, the goal is still to direct or guide attention towards and area of interest or an object/target, just as for AG, while the SVCs shall just be noticed when looking there anyway as a part of a regular scan pattern. AG is intended both to be perceived and to guide the operator the area of interest.

TABLE I
Different Concepts of Attention Support.

Concept	***Properties***
Alarm	Immediate attention and response
AG	Catching and directing attention, visible
SGD	Directing attention, but not to be noticed
SVC	Only to be noticed when looked at

IV. Method

The study focused on ATCOs but was complemented with input from VTS operators and train dispatchers evaluating similar designs in their environments, thus providing a cross domain perspective as well. These domain experts have an deep understanding of both the control processes to be handled, difficulties and possibilities, as well as the systems and visual environments. That is very important and the purpose of the qualitative approach was to capture their impressions with respect to their professional knowledge and experience.

Two types of sessions were held to gather feedback from the operators. In one type of session, data collection was performed at an ATC centre where four air traffic controllers participated in individual evaluations in close connection to their everyday work. The other type of session was a cross-domain operator workshop on the theme of adaptive automation were operators from three domains performed the same type of evaluation as the air traffic controllers at the ATC centre did, though at the workshop, the evaluation was made simultaneously (though individually) and the operators could discuss their experiences afterwards with each other.

A. Objects of Study and SVC Designs

Operator workshops, study visits, and studies of incident reports provided input to where in the operators' HMI SVC could be suitable, i.e. defining a certain object of study to evaluate the SVC concept. In all three domains, the chosen object of study were symbols in a certain part of the HMI. Thereafter, a set of different feedback types for SVC in the form of symbol property changes were agreed on and implemented in respective domain. The symbol property changes used were chosen based on them being distinct and easy to recognize [19], [21] and possible to combine with the original, unchanged symbols. Since the domains' prerequisites differed, different kind of property changes were chosen, even though with some overlap. All symbol property changes were gradual to avoid attracting peripheral attention.

To reduce the risk of technical difficulties and ensure that the different options were presented as consistently as possible to the different participants, simplified mock-ups were used instead of higher fidelity tools such as real time simulators.

1) ATC: For ATC, the chosen object of study was the presentation of conflicts in a so-called conflict and risk display (CARD). CARD is a tactical tool that visualizes conflicts and risks of conflicts detected by the medium-term conflict detection (MTCD) system in a separate window. Each conflict is represented by a square in a scatter plot diagram where the x-axis represents the time (minutes) until the aircraft conflicting reach the closest distance between each other, and the y-axis represents the calculated closest distance (in nautical miles) between the aircraft. The squares were the symbols that were subject to change. Even though being displayed in a separate window, and sometimes even on a secondary screen, the CARD is a tool used in the main task of keeping aircraft separated. At the other hand, it is one of many tools in the toolbox for identifying and evaluating conflicts, hence, how much it is used may differ both between different positions/sectors and between controllers. Five different symbol properties were considered suitable for modification as SVC (Table II).

Colour was initially considered a less good candidate. Even though generally easy to differentiate against other items, colours are already used a lot in the ATM system and in such an environment it may be hard to recognize [1]. However, at the same time, colour is a well-established concept and it was decided to keep it, not at least as for comparison. A mock-up of the CARD was created where the different symbol property

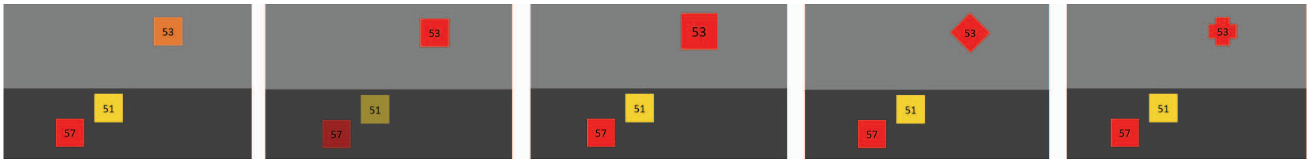

Fig. 4. Each square represent a conflict (red) or a risk for conflict (yellow) between two aircraft. The darker grey area is a help to identify minimum allowed lateral separation between the aircraft (5 NM), see also Fig. 5. The symbol property change is shown by the square in the upper right corner in each image. From left to right: Change of colour, opacity, size, rotation, and change of symbol (to one including intersection) respectively.

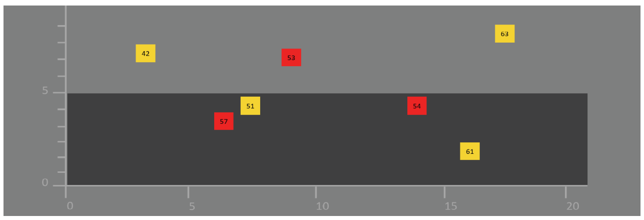

Fig. 5. Mock-up of the conflict (red squares) and risk (yellow squares) display (CARD) where each square represents a conflict between two aircraft. The y-axis is the minimum distance between the aircraft calculated by the air traffic management system and the x-axis is the time (in minutes) until the minimum distance occurs. The dark area marks 5 NM, which is a standard radar separation. In the study, each part of the test started with this basic image and a (remote controlled) button-click initiated the change. A delay of ten seconds where added before the change appeared and the change itself was configured to happen gradually with a duration of transformation of five seconds.

changes could be visualized Fig. 5. Fig. 4 shows the different variants of symbol property changes. Colour changed from red to orange, the opacity changed from 50% to 0% opacity, the size was increased to 130%, and the rotation was 45 degrees. Last but not least, the symbol got an intersect by changing to a cross where the width and height of the cross' arms were identical with the side of the square, thus keeping the outer size of the symbol constant (Fig. 4).

2) *Train Control and VTS:* For the complementary part from train control and VTS, sections on a digital rail plan and prediction vectors in the Electronic Chart Display and Information System (ECDIS) were chosen. The sections on the digital rail plan represent the status of a certain part of the rail system. The vector predicts the future position of a vessel given its current speed and heading. Both the rail segment and the prediction vector are represented as lines. However, the symbol property changes implemented as SVCs differed to suit the respective visual environments (Table II).

TABLE II
SYMBOL MODIFICATIONS.

CARD	Digital Rail Plan	ECDIS
Colour	Colour	Colour
Size	Size (width)	Size (width)
Opacity	Slowly pulsating colour	Dotted line
Intersecting element	Intersection (zig-zag line)	
Rotation		

B. Participants

A total of eleven operators participated in the study. Six ATCOs, three VTS operators, and two train dispatchers. Five of the ATCOs currently work operationally and all of them were well experienced (10 years plus). The four ATCOs from Stockholm ATC centre participating in the individual sessions all held valid ratings in sectors were CARD is used. The controllers at the workshop did not work operationally with CARD, but they were familiar with the principle of it and the ATM system in which it is used. Of the operators from the other domains, all were worked operationally, except one VTS operator, but with varying operational experience.

C. Procedure

The participants filled in an informed consent form, thereafter they were briefed about the project and the study. Since the intention was to catch their initial impression of the changes, they were only told that they should evaluate different types of reminding feedback without mentioning anything about the concept of SVCs as a gentle reminder. The instructions were read to the participants from a script.

The basic condition common to all domains was an important piece of information had been missed. The system had detected and concluded that a reminder would be proper.

After being presented to the prerequisites for the given situation, the operators where presented to the different symbol property changes. The variants were presented one at a time. A latin square distribution of order was used between the participants in the ATC domain were there were multiple individual evaluation sessions.

After each symbol change, they filled in a very short form where they ranked four statements about how they thought they would experience the change in the given situation with respect to intrusiveness. Followings statements (translated, originally in Swedish) were to be ranked: The symbol is intrusive, the symbol is discreet, and corresponding for the change of symbol. The rating was made on a on a ten degree scale where 1 = completely disagree and 10 = fully agree. To catch the participants first impressions, they were instructed to fill in the form without too much considering and with no discussions.

When the participants had seen all alternatives, they were presented to the idea of SVCs and asked to rate to what extent each symbol change fulfilled the intended purpose. The participants were presented with small cards, each representing one of the different designs. The participants than placed each

Fig. 6. Photo showing the cards representing the symbol changes presented to the ATCOs. They rated to what extent the symbol fulfilled the purpose of being a SVC by placing each CARD in a square- Placing a card to the far left meant that the participant did not agree at all with the statement, and vice versa for the far right position. Although giving a rating, the most valuable part of this was to get a starting point for them to reflect upon the SVC concept and the designs. The photo is an example to show the principle.

card on a scale printed on a paper with 12 squares were the leftmost square meant that the participant did agree at all with the statement that the symbol change was fit for purpose of being a SVC. Consequently, the rightmost square meant that the symbol change was considered fully fit for purpose. As a rule, they were only allowed to assign one card to each square, thus forcing the participants to decide on an order between the different symbol changes. They were allowed to rearrange the order until the session was ended if reconsidering while discussing (Fig. 6).

Last, but most important, was that the participants were instructed to motivate why they placed the card in a certain square or why they changed order. Once finished, a discussion followed where the participants had the opportunity to elaborate on what they thought about the concept of SVC and if there were other tools or parts of the HMI that would be suitable for the use of SVCs, thus proving the valuable expert views on the concept.

V. Results and Discussion

Most important from the collected data was the direct feedback from the operators about the SVC concept in relation to their domain. The subsections below will first present and discuss the results from the ATC domain, thereafter follows a comparison with the complementary results from the train control and VTS domains.

A. Air Traffic Control

The comments given by the ATCOs in the different sessions where collected and categorized into different groups of comments depending on what the comments related to (e.g. type of change). These comments are discussed below in relation to the fit for purpose ratings given for each symbol change.

The rating of being fit for purpose indicated the colour and opacity were considered less so than changes related to geometry of the symbol (Fig. 7). The colour change was considered a little bit too discreet,especially in relation to the overall HMI environment. Furthermore, it was pointed out that colours are already extensively used in the HMI for several purposes and adding more might not be a good idea. It was also mentioned that opacity and colour changes may be very hard to discover if there is only one symbol present. Even if the opacity could be hard to discover if alone, and in that sense discreet, it was considered to make the other objects look unimportant and call for too much attention to be a SVC. That was also indicated in the rating of intrusiveness of the different symbols, where opacity got higher ratings on being intrusive than the other symbols. Not much was said about size, and the few comments given were inconclusive. It was however rated as the least intrusive symbol and symbol change. Though not mentioned, a reflection is that the same problem of recognizing one single symbol would probably be valid for size as well as for colour and opacity. At the other hand, if only one symbol is present, one may argue that it is less likely to be missed. Rotation and intersect both got positive comments and were ranked as being most fit for purpose of SVC (Fig. 7). They were considered easily distinguishable, even if being alone. It was also mentioned that these kind of changes gave the impression that something should be done. The gradual symbol change received comments of being unnecessary or even unwanted and that it is more important to find the best cue design, but it can be discussed whether it was really possible to evaluate with the experiment setup used. This aspect has to be further investigated with real-time human-in-the loop simulations.

Fig. 7. Fit for purpose mean results, CARD symbol changes.

The comments about SVC as a concept were positive and it was not thought that it would add workload. However, there were some aspects pointed out that should be taken into consideration. The whole concept builds on the operators' scanning patterns. These are individual and so is the use of different tools, something emphasised by the ATCOs. A proposed solution was to have the SVC complemented with another cue in a less peripheral position indicating that something, not what, has been missed in the tool in question. This could also be coupled to the temporal dimension so that the complementary cue is only presented as urgency increases, i.e. escalation.

The idea of escalation may not be novel in itself but worth considering if taking the concept further and could be a way of connecting SVC with the more salient attention support concepts (Table I). As also pointed out though, one should be careful not to introduce too many different modes. Elaborating on that perspective, the real workload of the operator might also be taken into consideration so that the intensifying of the cue takes into account both the likelihood of the situation being recognized and the urgency, e.g. time to conflict or severity.

Bringing attention to blind spots was brought up as a possibility for use of SVC in other parts of the HMI. It was also mentioned that, specifically for the CARD tool, SVCs would probably be most useful for ATCOs working on a longer time horizon, especially when they are working in pairs with an executive ATCO (communicating with aircraft, working short term) and one planning ATCO (planning ahead).

B. Comparison to Train Control and VTS

When comparing the three different domains, it was hard to find results that favoured one, common type of symbol change as the best candidate for SVC. In the other domains, the symbol changes were generally considered too discreet and from the VTS domain it was said that they rather wanted something more like an alarm. There may be several reasons for this. The HMIs used from the different domains are not very similar with a more scattered HMI in the train control and VTS (which are more similar to the air situation display for the ATCO). Furthermore, the VTS operators are monitoring and giving traffic information in contrast to ATC, where the ATCOs are actively controlling the aircraft, hence more constantly staying in the same process and keeping SA. Also, the tempo of the processes differs a lot, e.g. turning a large ship takes a lot of time and the speeds are in tens of knots while the aircraft speeds are in hundreds of knots. The most important result here was that and it highlights the need for thorough analyses of the HMI in which the SVC shall be implemented and the prerequisites at hand. What might work very well as a SVC in one context may be less fit for purpose in another, and some time a visually stronger attention support concept may be more appropriate. This can be summarized as when deciding on the type of attention support (Table I) and type of soft visual cue (Table II), one has to consider the current visual context and the process context (Table III).

TABLE III
ATTENTION SUPPORT CONSIDERATIONS.

Context	Example
Visual	Current use of symbols and colours in HMI, screen setup.
Process	Process speed, type of control, work procedures.

VI. CONCLUSIONS AND FUTURE WORK

This paper presents *Soft Visual Ques* as a means to enable attention support recognizable when looking at an area of interest, while at the same time being subtle enough not to draw attention to other areas of importance, which complements the identified existing attention support concepts (Table I). Focus of the study was on air traffic controllers and the concept was evaluated in workshops with the conflict and resolution display tool. Enrolling real, subject matter experts provided an invaluable possibility to capture their views on *Soft Visual Ques* in relation to their own domain, something that would have been impossible in a traditional perception study with non-experts. The results of the feedback highlighted that the design is very much dependent on the environment (Table III) and that the design must be well balanced not to introduce just another alarm. Suggested future research is to perform real-time-human-in-the-loop experiments of the SVC concept, e.g. with focus on evaluation of the gradual change. Furthermore, more elaborated variants taking into consideration urgency level, operators state, and adaptation using the different attention support concepts (Table I) with different visual strength would also be of great interest to explore.

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