Topic 5: Battlespace understanding and management

Enhancing change detection of the unexpected in monitoring tasks – guiding visual attention in command and control assessment

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Abstract

Many surveillance tasks in military command and control involve monitoring for change in a visual display environment in order to discover potential hazards or new opportunities. Effective change detection in various situational pictures is a requisite for battlespace understanding. The detection of unexpected events is particularly difficult and missed events may cause malicious outcomes in contexts characterized by high levels of complexity and risk. We present examples of change detection failures in the military domain, and explain why and how the psychological phenomena of change blindness and inattentional blindness can generate such failures. We further give an overview of existing solutions to these problems and point out a specific issue, coping with unexpected events, where effective solutions are missing today. Inadequate expectations may be a result of misdirection by the enemy. This article demonstrates a new concept – an adaptive attention aware system (A3S) for enhanced change detection. The A3S is a concept of gentle support. It is based on cuing of visual attention by a non-obtrusive flash cue in the display (bottom-up), to compensate for guidance by inadequate expectations (top-down) in situations influenced by high levels of uncertainty.

Introduction

In our everyday lives, we are largely unaware of objects and events in the environment, especially if they are unexpected. This fact comes as a surprise to most people since our intuition tells us that our perception is comprehensive and close to complete. Most of the time, our limited attentional capacity is not a substantial problem because humans have evolved to focus attention on relevant aspects in our field of view. However, that is not the case when we regard the complex and high-risk tasks carried out by human operators in military command and control (C2). In these cases, the failures of change detection when monitoring various situational pictures are problems that may lead to lethal outcomes (fratricide, missed enemy actions, etc.).

The purpose of this paper is to present examples of change detection failures in safety critical domains with an emphasis on military C2, to explain why these problems occur, to present existing guidelines for solutions and why they do not suffice, and finally introduce a new concept for enhanced change detection. Thus, the research question investigated in this paper is:

How can change detection of the unexpected be enhanced in military C2?

Operational definitions

C2: We adopt the perspective on C2 given in Brehmer (2010) that C2 is "*a human activity that aims at solving (military) problems*. Put differently, C2 is concerned with *design and execution of courses of action* to achieve (military) goals". Using design logic (purpose, function and form), the purpose of a C2 system is "*to provide direction and coordination for the force".* The necessary functions to achieve this purpose are given in the model of C2 in figure 1 below. In this paper we focus on the input and output from the functions of data collection and orientation.
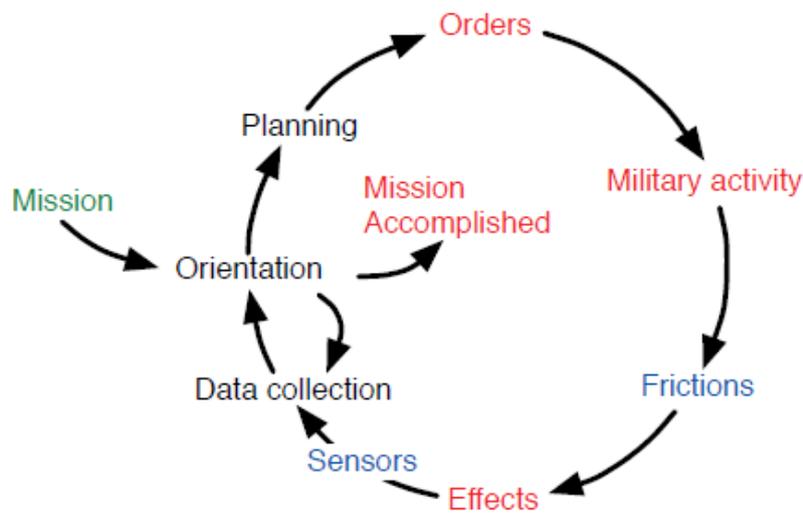
Figure 1 (Persson, 2014, p. 38, reprinted with permission from the author). "The Dynamic OODA-loop. Red indicates products, black functions, green input and blue "filters" that affect what passes from function or product to another function or product" (Brehmer, 2010).

*Assessmen*t: At the design level of form, various expressions of C2-processes are to be found. One example is the *operations assessment process:* "The activity that enables the measurement of progress and results of operations in a military context, and the subsequent development of conclusions and recommendations in support of decision-making" (NATO, 2013). We consider the task of change detection (see below) to be essential to the operations assessment process and also to the knowledge development process as specified by NATO (2013).

Change detection: The task of specific focus in this paper is appropriate to divide into three concrete and measurable parts:

1. Detection (Has something changed? The question is answered by either a "yes" or a "no".)
2. Localization (Where has the change occurred? The question is answered by indication of a position.)
3. Identification (What / who has changed? The question is answered by a classification such as "hostile".)

Change blindness (CB): is defined as "the surprising difficulty observers have in noticing large changes to visual scenes" (Simons & Rensink, 2005, p. 16).

Inattentional blindness (IB): is defined as "the failure to notice a fully-visible, but unexpected object because attention was engaged on another task, event, or object" (Simons, 2007, p. 1).

Complex: the term is used with reference to high levels of variability and dynamics in the system which a controller seeks to control. High levels of variability are in turn the result of many elements which are related and interact with each other in unexpected ways. High levels of dynamics refer to the tempo of which the systems elements change their status. Hence, a shortage of time and predictability are the signs of complexity.

Uncertainty: The lack of time and predictability may cause an experience of *uncertainty* on the controller's behalf.

Risk: In this paper the concept of risk, is used in a general sense as stated by the Oxford English Dictionary, and reviewed by Aven (2012, p. 35): "(Exposure to) the possibility of loss, damage, injury, or other adverse or unwelcome circumstances; a chance or situation involving such a possibility".

Delimitations

The primary units of analysis in this work are the human operator, the detection task, the technology of displays and visualizations used as means to solve the task, and the complex and high risk context of C2 in which the task is conducted. This article focuses on the individual operator performing a detection task in a digital display environment. An individual operator focus is an obvious delimitation. Many detection tasks in complex and high risk contexts are performed in a social context where individuals work together as teams to solve the tasks. However, since a team-focus would need to include a set of other mechanisms than the ones traditionally identified in studies of the phenomena of interest (CB and IB), it was considered to be beyond available resources in this paper. There are other phenomena in the fields of perception and attention that may influence change detection as well; the attentional blink, repetition blindness, and inhibition of return. We have considered them to be beyond the scope of this article though. For a recent review of the relation between perception and attention see Rensink (2013).

Command and control – a complex and high risk context

Military C2 (for a recent review, see Persson, 2014, pp. 32-43) is dependent on effective and efficient change detection.[1] The reason for this becomes apparent when considering the core of military C2; namely, *dynamic decision making* (e.g., see Brehmer & Thunholm, 2011). According to Brehmer (2000, p. 234) a dynamic decision problem has several core properties, one being: "The state of the environment changes, both autonomously (for example, as a consequence of enemy actions) and because of the decision maker's own actions". In the conquest of controlling the operational environment, any party of the conflict must be able to adequately perceive changes in the state of the environment which are (or might be) of importance to their own task, plan and goal. Detection of such changes is the first necessary step towards an adequate perception and comprehension of the situation at hand – understanding the battlespace.

Today all kinds of different sensors are able to collect data from the conflict arena and transmitting the data to technically advanced command posts. At least this is true when resourceful actors of a potential conflict are considered. In command posts, collected data are refined and presented according to the operators' specifications and thus providing high levels of situation awareness (SA) to the decision maker. For a definition and a description of SA, see Endsley (1995). The described chain of information flow, from events in the operational environment via sensors and command posts, all the way to the commander, seems straight forward and without any major obstacles. Or, is it really?

The overarching problem is that although immense amounts of data can be made available to human operators, there are no guarantees that the most appropriate data are attended and selected relative the situation at hand. Selection will occur at different levels, when sensors are directed, but

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[1] Effective: the extent to which a goal, or task, is achieved. Efficient: amount of effort required to accomplish the goal. These criteria are based on the International Standard Organization's definition on usability (ISO9241-11, 1998).

also as the perceptual selection in the interaction between human operators' and the visual display systems in command posts. How does the perceptual selection of data work then? This question is fundamental to all of us which Theeuwes (2010b, p. 138) points out: "Are we in control of selection or is the environment telling our brain what to select?" The complexity in C2 is enforced by two domain-specific variables: (a) the existence of a human adversary – inflicting the possibility of deception (compare with the line of IB termed misdirection presented below), and (b) the fact that parties in the conflict can be very difficult to classify (e.g., targets or non-targets) in some types of warfare such as irregular warfare (IW)[2]. To sum up; there is a need for more agile solutions in C2 (Alberts, 2011) to cope with the increased complexity.

Change detection failures in C2 and other safety critical domains related to CB

In this section and the following, examples of change detection failures with direct relevance to C2 and safety critical activities are presented. These cases include either real life practitioners/experts who participated and/or (technical) contexts directly linked to real operational systems.

Divita, Obermayer, Nugent, and Linville (2004) performed an experiment to determine whether CB occurred when experienced operators of naval Combat Information Center (CIC) consoles monitored a tactical situation display for task-relevant changes in air traffic. Four types of attribute changes to objects were used: (a) course, (b) speed, (c) range, and (d) bearing. In addition to attribute changes new objects ("contacts") could appear on the display for the first time. The display contained eight simultaneous contacts and responses were given by mouse-clicking on the contact after blanking of the tactical display. Information about type of change was presented on a secondary alert display placed side by side to the tactical display. Participants were informed about the CB phenomenon and the purpose of the experiment beforehand. Still, results showed that about 1/3 of the critical trials required two or more responses to correctly identify a changed contact; thus, the conclusion was made that CB indeed does occur in the CIC environment.

Durlach and Chen (2003) studied the effects of secondary tasks on change detection performance in the context of the fielded army system: Force XXI Battle Command Brigade and Below (FBCB2) which for example is used to support a common operational picture. Participants were tasked to report changes regarding appearance, disappearance, position, shape, and color of the presented icons. A maximum of two icons was present on the display and only one of them could change. The participants were also instructed to manage complementary tasks like sending text messages via separate windows which occasionally were superimposed on the tactical map. When changes occurred during a distractor task the detection rates were only about 50% (regarding position, shape, and color).

Durlach, Kring and Bowens (2008) used a modified version of the FBCB2 system to assess how simultaneous changes (appearance and disappearance) of military icons (nine red, nine blue, and

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[2] IW is one of several terms that aim at classifying war by the methods of warfare. Examples of these dichotomies are; symmetric and asymmetric, conventional and unconventional, regular and irregular war (Angstrom & Widen, 2015, p. 27). IW is defined by Kiras, 2008, p. 232 as; "the use of violence by sub-state actors or groups within states for political purposes of achieving power, control and legitimacy, using unorthodox or unconventional approaches to warfare owing to a fundamental weakness in resources or capabilities". One instance of IW is insurgency and thus the activities conducted to defeat the insurgents are termed COIN (e.g., see Kiras, 2008, p. 263).

nine yellow at the start of each trial) affected change detection performance. The results revealed a detection rate of: (a) one icon = 79%, (b) two icons = 59% and (c) three icons = 37%. Thus, Durlach et al. (2008) concluded that a significant effect of simultaneous changes was evident.

Vachon, Vallieres, Jones, and Tremblay (2012) measured performance in an "implicit change detection" task in a C2 context with dynamic displays. Implicit change detection was defined as: "the detection of critical changes to the situation is intrinsic to the operator's mission and does not require any explicit report of change" (p. 997). A micro-world called Simulated Combat Control System was used: "a functional simulation of the cognitive activities performed by a tactical coordinator aboard a ship, such as the threat-evaluation and combat-power management processes" (p. 997). The participants were tasked to assess: (a) "the level of threat" and (b) "the threat immediacy". The third task (c) was "to defend the ship" (p. 998-1000). The interface consisted of a radar display with the own ship in the central point and up to 10 aircrafts in the surrounding radar screen. Each aircraft object had 11 related parameters presented in a separate window (the symbol itself in the radar display indicated three of these parameters: identity [non-hostile, uncertain, and hostile], speed and trajectory). The third part of the interface was a window containing response or action buttons related to the different subtasks mentioned above (a-c). After training sessions, participants executed four blocks of four scenarios lasting four minutes each. Every scenario contained eight critical changes which were defined as critical when four or five specific parameters (out of the eleven mentioned above) indicated threatening cues (hostile aircraft). If a participant responded (selected and/or classified an aircraft) within 15 s after a critical change, it was considered detected.

The results showed an aggregate change detection failure rate of 13.1%. Moreover, the results also revealed the significant importance of eye fixation on the changed aircraft, both before the change (within 5 s before change) and after (within 15 s after change). For example, the detection failure rate regarding pre-change, non-fixated aircrafts was 19.8%. In addition, the effect of gaze position on change detection was measured. They found a significant increase of detection failure as a function of distance between gaze position and the position of the critical change. Last, results indicated that pupil size increased when changes were fixated but undetected. The conclusion was made that one source of CB (beside the more intuitive "no attention" source) could be generated by the automatic or unconscious attentional efforts (indicated by pupil dilation) related to fixated but undetected aircrafts – "this attention-failure source of CB is believed to be more specific to complex dynamic situations" (p. 1004).

Studies from other safety critical domains have also demonstrated substantial failures of change detection in relation to CB. There are examples from aviation (Varakin & Levin, 2004; Nicolic & Sarter, 2001; Wickens & Alexander, 2009), and from road traffic (Galpin, Underwood & Crundall, 2009; White & Card, 2010).

Change detection failures in C2 and other safety critical domains related to IB

Chabris and Simons (2010, p. 11-12) gave a vivid description to what happened in the waters near Hawaii in February 9, 2001:

> [C]ommander Scott Waddle, captaining the nuclear submarine *USS Greenville* near
> Hawaii, ordered a surprise maneuver known as an "emergency deep," in which the

submarine suddenly dives. He followed this with an "emergency main ballast tank blow," in which high-pressure air forces water from the main ballasts, causing the submarine to surface as fast as it can. In this kind of maneuver, […] the bow of the submarine actually heaves out of the water. As the Greenville zoomed toward the surface, the crew and passengers heard a loud noise, and the entire ship shook. […] His ship had surfaced, at high speed, directly under a Japanese fishing vessel, the *Ehime Maru*. The Greenville's rudder, which had been specially reinforced for penetrating ice packs in the Arctic, sliced the fishing boat's hull from one side to the other. Diesel fuel began to leak and the *Ehime Maru* took on water. Within minutes, it tip up and sank by its stern as the people onboard scrambled forward toward the bow. Many of them reached the three lifeboats and were rescued, but three crew members and six passengers died. The *Greenville* received only minor damage, and no one onboard was injured.

In the investigations following this tragic accident it stood clear that the Commander and the officer of the deck had made, according to standard procedure, a periscope scan to confirm the surface was clear before making the maneuver. Chabris and Simons (2010, p. 13) concluded:

> But the results of our gorilla experiment tell us that the *USS Greenville's* commanding officer, with all his experience and expertise, could indeed have looked right at another ship and just not have seen it. The key lies in what he thought he would see when he looked: As he said later, "I wasn't looking for it, nor did I expect it".

Spak and Lind (2011) experimentally investigated the effect of a subtle change in the monitoring instruction, in a change detection paradigm, to participants specialized in C2 and military intelligence. The authors concluded: "If the contextual circumstances are characterized by high levels of uncertainty about the different parties in a conflict, then there is a severe risk of missing important information due to a too focused/selective differentiation about what information to detect".

Studies from other safety critical domains have also demonstrated substantial failures of change detection in relation to IB. There are examples from healthcare (Drew, Võ & Wolfe, 2013), from road traffic (Herslund & Jørgensen, 2003; Koustanaï et al., 2008), and from aviation (Fisher, Haines & Price, 1980). We have so far presented numerous examples of change detection failures from military C2 and other safety critical domains. Next we will examine why these problems occur.

Seeing without noticing – change blindness (CB)

Maybe the most obvious and most severe effect in monitoring tasks is to miss important and relevant changes in the environment. Imagine yourself in the professional role of an operator in a C2 facility with visual surveillance as your primary task in a digital display environment. Your specific job is to observe and report anomalies at the headquarter checkpoint. A normal or standard event could be as follows: In your main display you notice a person that steps up to the microphone at the checkpoint presenting himself as a messenger seeking clearance to pass. You ask him to present an identity card in the small box just beside him. The camera in the box sends the picture of the identity card to a separate display placed at the side of your main display. You look carefully at the picture and note down the data on a piece of paper. This procedure lasts for say ten seconds. When you are finished, you look at the messenger in the main display and inform that he is free to pass through.

This marks the end of this fictitious event. Now, surely you would have noticed if the messenger had changed into another person (maybe an imposter?) while you were attending the identity card display? If you would answer affirmative on that question you would share the opinion of most people. Thus, surprising to many people, there is a solid ground of scientific work that present results in an opposite direction (e.g., Levin & Simons, 1997; Simons & Levin, 1998).

This psychological phenomenon is named *change blindness* (CB) and can be regarded as the opposite to change detection. CB is "the surprising difficulty observers have in noticing large changes to visual scenes" (Simons & Rensink, 2005, p. 16). The word "surprising" adverts to the fact that many people vastly overestimate their change detection ability, and the term large refers to if the pre-change scene and the post-change scene are easily discriminable when viewed side by side (Levin, Momen, Drivdahl, & Simons, 2000). CB is typically induced by some type of temporal interrupt that often causes the observer problems to detect changes occurring between the scene/view/picture/representation before and after the interruption (see Rensink, 2002; Jensen, Yao, Street & Simons, 2011 for reviews). The types of interruptions can vary between eye movements (saccades), eye blinks, a brief blank screen or other visual occlusions or simultaneous perceptual events such as abrupt onsets/offsets of color and luminance. Hollingworth (2006) concluded that CB has three causes:

> (1) because they have not fixated and attended the changing object prior to the change and thus have not had an opportunity to encode information sufficient to detect a change, (2) because they have not retrieved or adequately compared a memory representation to current perceptual information[.]

We would like to remark though that the third point put forward by Hollingworth (2006) below is technically not a cause of CB resulting from the fact that small changes (below threshold) would not be surprising or large as described in the definition of CB.

> (3) because, for many comparisons, evidence of discrepancy falls below threshold for signalling a change in the world.

Rensink, O'Regan and Clark (1997) as well as Hollingworth (2002, 2003) presented evidence of the crucial importance of attending objects before scene interruptions to perform effective change detection. The knowledge base of CB literature presents the requirements of five necessary steps for effective change detection (Jensen et al., 2011, p. 534):

> 1. Direct attention to the change location.
>
> 2. Encode into memory what was at the target location before the change.
>
> 3. Encode what is at the target location after the change.
>
> 4. Compare what you represented from the target location before the change to what was there after the change.
>
> 5. Consciously recognize the discrepancy.

Regarding the first point, we emphasize that attention is a requisite for change detection but it is not a guarantee for avoiding CB (O´Regan, Deubel, Clark, & Rensink, 2000).

Seeing without noticing – inattentional blindness (IB)

It is even more obvious that attention plays a decisive role in change detection when a closely related phenomenon to CB; namely, *inattentional blindness* (IB) is considered. Simons (2007, p. 1) defined IB as: "the failure to notice a fully-visible, but unexpected object because attention was engaged on another task, event, or object". Even though the two phenomena share the effect of generating perceptual failures of events happening right in front of our eyes in plain sight, there are important differences (Rensink, 2000; Jensen et al., 2011):

- A central distinction between CB and IB is that CB occurs because of changes between two different scenes with a temporal interrupt between them, whilst in IB the change happens right in front of the observers' view but still goes unnoticed because attention is directed or oriented elsewhere in the display.
- In IB attention is directed by a more or less demanding *task*, which is however, not the case in CB.
- In IB the changed item is unexpected (but distinctive once noticed) while in CB the observer may very well know what to look for.
- CB requires memory to compare the before- and after change representation but IB does not.

Basic research examples of IB are described in Mack and Rock (1998) where participants in a computerized study were instructed to judge whether the horizontal or the vertical parts of a cross were the longest. On the critical trials, an unexpected object appeared in one of the cross quadrants. About 25% of the subjects were unaware of the unexpected object independent of its color, shape, or motion. In addition, Simons and Chabris (1999) extended the results above in a more natural setting to include sustained IB in a dynamic environment. The authors presented data where subjects missed a salient object, a person wearing a gorilla suit, at about 50% level even though the "gorilla" walked across the scene for 9 seconds and thumped its chest in the middle of the scene facing the camera. The subjects' task was to count passes with a basketball between three players in the scene.[3]

One specific strand or line of IB is *misdirection* (e.g., Kuhn, Amlani & Rensink, 2008). The term was coined in the context of magic and the performance of magicians. It was defined as: "the diversion of attention away from its method" (p. 349). A close relationship between IB and misdirection is proposed by Kuhn and Tatler (2011), however; criticized by Memmert (2010). In the light of the arguments put forward by Memmert (2010), Most (2010) concluded that IB could be divided into two sub-types of IB, *spatial IB* and *central IB* where misdirection is more strongly linked to spatial IB as exemplified by Kuhn & Tatler, 2011, p. 432: "the magician systematically orchestrates the observer's attention, which results in the failure to see a fully visible event". Meanwhile, central IB relates to the mechanism of a more or less demanding primary task as in the classic gorilla experiment above (counting the passes). We consider misdirection/spatial IB to be important because of the inclusion of a manipulating actor or operator (e.g., the magician). The reason for this comes clear in relation to the overall context of this paper, military C2 in complex operational environments, where sometimes a human adversary is trying to manipulate your attention and perception of the situation.

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[3] This study was built on original research by Neisser and Becklen (1975) on selective looking.

If the reader returns to the fictitious event with the messenger above and apply an IB perspective, then an unexpected item would appear in the main display without the operator noticing it despite looking straight into the display. A probable reason for this could be the operator focusing visual attention on the face of the messenger while not selecting information on the occurrence of for instance a person wearing a gorilla suit passing behind the messenger in the display. This would be an example of central IB where the primary task is identification by looking at the messenger's face. If instead the messenger would have misdirected the operator's attention by some means (e.g., pointing at something) this would have been a case of spatial IB.

The level of task difficulty or perceptual load of the primary task is also relevant for the amount of IB and CB found (see Lavie, Beck, & Konstantinou, 2014).

Guiding visual attention

To enhance change detection when an operator is performing a complex operational task that demands visual attention raises the question: how is attention guided or oriented? From the large body of research on attention (see for instance James, 1890/1950, p. 416; Posner, 1980; Corbetta & Shulman, 2002; Theeuwes, 2010a), and a recent review of the relation between perception and attention (Rensink, 2013), we can summarize the current view as follows: attention can be either directed by cognitive factors like goals, intentions, expectations, and knowledge (the term top-down will be used from here to represent this perspective of orienting) or by perceptual factors such as the salience of stimuli/objects in the external world/display/scene (the term bottom-up will be used from here to represent this view of orienting).

Posner (1980) presented and validated an elegant way to create an expectation by the observer about where attention should be oriented to detect a target object. He used a central symbolic arrow cue, with a validity of 0.8. In the cases when the arrow was not valid, the observers thus had a faulty expectation of where the object of interest would be. This indicates a possible method of investigating change detection of the unexpected. Posner (1980) and Jonides (1981) also revealed the possibilities to orient attention by a peripheral (bottom-up) cue. Furthermore, studies show that an automatic shift of visual attention by peripheral cues in terms of abrupt onsets or offsets (bottom-up) can occur on a systematic basis (Yantis & Jonides, 1984; Müller & Rabbitt, 1989). This invites us to the potential possibilities of capturing an operator's attention by such bottom-up factors. Other early studies showed results that were opposing these conclusions (Yantis & Jonides, 1990; Theeuwes, 1991) indicating that subjects´ intensions could resist shifts induced by abrupt onsets or offsets. This vivid discourse has continued until recent and the precise relation between top-down and bottom-up orienting is still debated (Theeuwes, 2010a,b; Andersson & Folk, 2010; Folk & Remington, 2010).

Present guidelines for enhanced change detection and why they don´t suffice

There are a fair number of general guidelines in the literature on how to enhance change detection proposed from different perspectives such as Human Computer Interaction (e.g., Durlach, 2004, p. 447; McFarlane & Latorella, 2002, pp. 46-49 [coping with interruptions]), and from information visualization and computer graphics (e.g., Healey & Enns, 2012, p. 1184; Rensink 2002b, 2007; Rensink, 2011, pp. 74-87). Some of the more specific solutions include the use of visual cues in applied contexts (e.g., Nicolic & Sarter, 2001; Tappan et. al., 2009; Crebolder, 2012), and dedicated change detection tools (e.g., St. John & Smallman, 2008; Mancero, 2010).

St. John and Smallman (2008) recommend automatic change detection algorithms in the tool: The Change History EXplicit (CHEX)[4], with the purpose of enhancing change detection in an air warfare task. According to the authors, the significant design features of CHEX are (pp. 126-127): "(a) changes are detected automatically and available for review at any time, (b) change notification is minimally distracting to ongoing tasks because changes are logged to a peripheral table rather than directly on the situation display"[.] Yet, two additional features are added to the list: "(c) the table can be scanned quickly or sorted to help users prioritize their reviews of changes, and (d) changes do not clutter the already busy situation display because they are available only on demand on the situation display".

All guidelines and recommendations presented above rest on the assumption that operators know what to detect. Presumably this applies to situations characterized by low levels of complexity and uncertainty. The reader has already learned from previous sections that interruptions may cause severe CB despite the operator being aware of what to detect in safety critical tasks. Therefore, the presented guidelines are valid in this more predictable context. However, this paper has also reviewed the occurrence of serious accidents owed to inadequate expectations - the unpredictable and uncertain conditions where IB can affect the outcomes of operators' perception. There are few suggestions in the literature on how to detect the unexpected when it comes to monitoring tasks in digital display environments. The design challenge is that any suggested design solution must be able to support efficient change detection in contexts plagued by *both* CB and IB. This is so because the predictability about the observed environment may vary or shift; sometimes operators will know what to detect, sometimes they will not. Next, we will present a concept that specifically deals with this challenge.

An adaptive attention aware system

We propose an *adaptive attention aware system*, A3S (Roda & Thomas, 2006) - where the operator is gently guided by the display system in order to keep spatial distribution of his/her attentional resources thereby reducing the risk of biased search and thus change detection failures. Input to the system will come from two sources: the first source is data picked up by sensors and the second is eye-tracker data on the operator scanning behavior (e.g., Räihä, Hyrskykari & Majaranta, 2011). Usually, the A3S would be tuned for a combination of the data-sources. The relative impact from each data-source could be adapted and tuned according to the particular situation. The screen needs to be divided into different areas so that every pixel belongs to only one area, the simplest case is a grid-like arrangement[5]. The activation rule would then be: IF potential targets change (appear, disappear, or move) in area X of the screen AND the operator dwell time has been zero in area X for a predefined time-period, THEN the A3S triggers an abrupt onset visual cue in area X. The position of

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[4] See Smallman and St. John (2003) for the origin of the CHEX tool.
[5] An anonymous reviewer posed a relevant question, on an earlier draft of this paper, about the potential impact on the A3S regarding the accuracy and precision of the eye-tracker device. We estimate that detailed technical specifications about the eye-tracker device must be developed for specific future use cases. Indeed, this is one of the proposed future research activities we suggest, well worth a paper of its own. A general minimum requirement though, is the capacity to register fixations of the operator´s eyes on the display. This capacity will for example depend on known errors to accuracy such as: illumination in the environment, operator and stimuli properties, calibration procedures and eye position in relation to the display (e.g., Tobii, 2016).

the cue would be directly associated with the potential target - that is on target position or in close proximity to the target position, see figure 2.
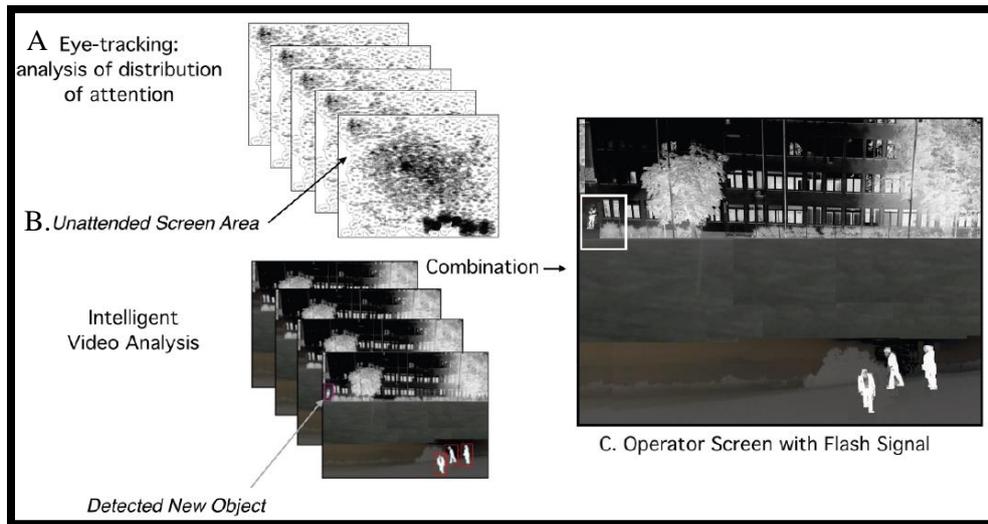

Figure 2. A sequence of pictures representing the two-piped input to the A3S. In (A) the data coming from the eye-tracker is shown. Note the unattended area to the left and the highly attended area below to the right. In (B) the thermal sensor have registered four potential intruders. In (C) the A3S has fusioned the data from A and B, and a visual flash cue is triggered at the unattended potential intruder to the left (adapted from Spak, 2015, p.67).

Imagine your task is to gather intelligence from a city square with the thermal sensors from an unmanned aerial vehicle (UAV) at night. The picture you are monitoring on your command post display is characterized by a dark and grey background where you can vaguely see streets and buildings. Every entity that is emitting heat is represented as distinct bright objects in the screen. These objects are people, animals, or motor vehicles moving around, and one of these bright blobs may be an enemy sniper. A car that stops in the middle of a street captures your attention. Several people jump out and move fast towards a building nearby and you are intensively following what will happen next. At another part of the display, a bright figure gradually appears on top of a roof and two seconds later another moving figure suddenly falls down in an alley.

Why did you not detect the sniper on the roof? A plausible answer is; because it is extremely difficult to be aware of events outside focused attention. In this case, the operator zoomed in attention on the stopped motor vehicle and locked on this event for some time. Therefore, other events occurred unnoticed, including a sniper on the roof – a case of IB (spatial IB). Would your chances have been better with the support of an A3S? The answer would be yes given certain premises. First, the A3S would be tuned and set for the current level of uncertainty. Second, there should be no other constraining rule for where the operator should pay more or less attention. That is, the operator should give every event an (approximately) equal amount of attention. Third the operator would be well aware of the A3S existence and functionality (which would include the authority to recalibrate or temporarily turn the system off). The activation rule would be triggered because: a potential target appeared in the roof area of the screen AND the operator dwell time had been zero in that area for more than the predefined time-period. The A3S would then display an abrupt onset visual cue in close proximity to the object on the roof, more or less automatically attracting the attention of

the operator. If the event rate would be moderate to high, the A3S could make use of both input sources. But at very high or very low event rates the system would only be using input from the eye-tracking channel. Consider the same situation as above but this time you are monitoring the same square in full daylight with signals coming from a video camera positioned on a roof. Many people are milling around the square and your task is to detect and localize potential terrorists. Here, the A3S would only be using input from the eye-tracking channel since the event rate from the sensors would be so high that visual cues related to each event would only create more clutter on the already busy display. Instead, the A3S would trigger the operator to scan areas of the screen that has had no attention at all for some time, see figure 3.
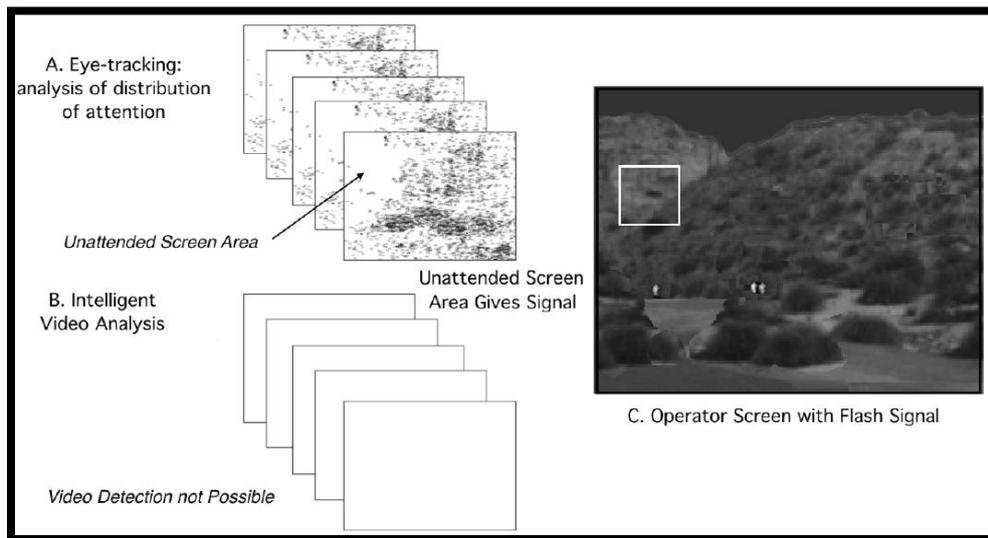

Figure 3. A sequence of pictures representing the input to the A3S. In (A) the data coming from the eye-tracker is shown. Note the unattended area to the left. In (B) the sensor stream has been deactivated. In (C) the A3S only uses the data from (A), and a visual flash cue is triggered to sustain an adequate scan-path in the display (adapted from Spak, 2015, p.69).

In the case when there are very few events over time there is a risk of vigilance problems (e.g., see Hollands & Wickens, 1999, pp. 34-44). The A3S could then similarly aid the operator to keep up a sufficient level of attention despite the low event rate by adequately orienting visual attention. When targets are very well defined, the A3S could use only the event-driven sensor data and the system would resemble a more traditional notification support.

Discussion

Naturally, the A3S needs to be thoroughly evaluated before any implementation in applied settings can be done. However, the core component of the system, the visual cue, has already been evaluated in a series of three experiments in a context of a simulated radar screen (Spak, 2015; Spak, 2016, in preparation). After all; the A3S rests on the assumption that the visual cue actually captures the operators' visual attention. Spak (2015) reports: "(b) the bottom-up flash cue enhance change detection independent of perceptual load, (c) the flash cue enhance change detection in both static and dynamic environments, and (d) the flash cue is beneficial for change detection even when its position is outside foveal vision in relation to the changed target object".

How general is the A3S concept then? Does it for instance apply on all levels of command? On the one hand, we argue that the functionality of the A3S would be independent of command level because human operators are involved at each level, and the problems in change detection (CB and IB) are directly connected to human performance. On the other hand, it is likely that the level of complexity (in turn dependent on the level of dynamics) may vary between the command levels, hence making the level of difficulty in change detection to fluctuate. We conclude, taking both arguments together, that the A3S concept would indeed generalize over command levels. This is so, because the varying level of complexity is exactly what the A3S is designed to handle.

We conclude that an adaptive attention aware system, equipped with the necessary features for an adequate orientation of operators' visual attention as presented here, is a concept well suited for enhancing change detection of the unexpected in a complex and high risk context. Does this imply that a remedy to change detection failures is actually found? Just as paying attention to something before it changes during an interrupt is not a guarantee for perfect change detection performance, the use of an A3S is not a guarantee for perfect change detection of unexpected objects and events either. However, just as paying attention to something before it changes is a necessity for change detection, and also raises the chance for change detection, the use of an A3S would likely raise the chance for change detection of unexpected objects and events. The output from this paper reveals new opportunities for operators engaged in visual change detection, in situations characterized of raised levels of complexity and risk. It is plausible that the A3S supports an adequate orientation of visual attention that facilitates the detection of the unexpected and improves battlespace understanding. Thereby, designers can boost the relative control of perceptual selection in favor of the operator and reduce the risk of deception by an illusory adversary.

Future research

First; we consider research about how to quantify the level of complexity in the observed system of interest, to be of significant importance. This is necessary to reach satisfying calibration of the A3S. Second; an evaluation of the A3S as a whole is called for, including well defined use cases. Third; a methodology for measuring CB and IB in the field at C2 facilities would be most useful. Fourth; to develop a methodology for measuring CB and IB in C2 teams would be of high relevance for C2 research.

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