Representing Three-Dimensional Airspace on a Two-Dimensional screen

Visualizing altitude information on a radar screen for a decreased cognitive load

LUKAS LINDAHL
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ABSTRACT
This study was conducted at the Swedish Defense research agency as an attempt to understand affordances and limitations in visualizing altitude information for fighter controllers. The fighter controllers are subject to large quantities of numerical information, from multiple sources simultaneously. Their duties are highly stressful and require large mental workload and situational awareness. Today, a large portion of information is represented visually except for altitude. The altitude of a jet is represented only numerically on the screen, next to the icon representing an airplane. This thesis attempts to aid the users in their tasks, by determining if interactive visual information could benefit the current system.

This study resulted in one prototype, where height was represented in three different ways, one using color coordination one using different sizes and one mimicked the current numerical representation. These variations were evaluated in a user study, consisting of semi structured interviews along with benchmark tests. None of the suggested visual cues could be demonstrated as more efficient than the current representation, but a majority of participants preferred the version using varying sizes as this was considered more intuitive and held less limitations than the other version. Future research is encouraged as to successfully determine if altitude information can be visually represented for a decreased mental workload.

SAMMANFATTNING

Denna studie resulterade i en prototyp, i vilken höjd representerades på tre olika sätt. Genom färg med varierande opacitet, genom olika storlekar på objekten, samt den nuvarande numeriska metoden. Dessa versioner utvärderades i en användarstudie, bestående av semistrukturerade intervjuer samt benchmark test. Ingen av de föreslagna visualiseringarna kunde påvisas mer effektiv än det nuvarande systemet, men en majoritet av deltagarna föredrog versionen med varierande storlekar, eftersom detta ansågs mer intuitivt samt hade färre begränsningar. Vidare studier uppmanas för att med framgång avgöra om altituden kan representeras visuellt, för en minskad mental belastning.
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Author Keywords
Mental workload; Cognitive load; Fighter controller; Air traffic controller; Visualization; Radar; Intuitiveness

ACM Classification Keywords
H.5.2 [Information interfaces and presentation] User Interfaces – Screen design

INTRODUCTION
Since its establishment in 1926, the Swedish Air Force is an integral part of the nation’s armed forces; conducting international missions and surveilling the Swedish border. Fighter pilots are dependent on orders and information received from fighter controllers, who are specialist officers, responsible for guiding military aircraft and in-flight aviation safety [10]. The fighter controller’s skill set is unique. They are subject to large quantities of constantly changing numerical data, having to process both verbal and written input in order to perform quick and safe decisions [9]. The work environment is highly stressful and requires great situational awareness. Today, fighter controllers are limited to a radar screen where altitude is only referred to as an absolute numerical value, which means, the user needs to read each number individually to get an accurate understanding of three dimensional locations in the airspace. Height is not only important as an absolute value. In a combat situation, the altitude relation between jets is highly relevant, as the higher one is in a naturally advantageous position.

Having military aircraft in flight is associated with both economic expenses along with an exposure to incidents. Therefore, for practicing tactical scenarios, pilots and fighter controllers make use of simulators. The Swedish Air Force’s Combat Simulation Centre (further referred to by its Swedish abbreviation FLSC) provides an opportunity for up to twelve pilots to engage in tactical training in simulators, with fighter controller’s guidance. After-action review increases understanding and learning in a cost-efficient and risk-free environment.

Providing information visually is a common approach to increase understanding of complex data, yet there have been few attempts on doing so in the specific field of fighter control. At the Swedish Defense Research Agency (further referred to by its Swedish abbreviation FOI), attempts at studying visual patterns and mental workload among pilots have previously been conducted [2]. Providing fighter controllers with a visual aid to pre-attentively understand which jets are on a higher altitude could have a positive impact on their cognitive load. As a result, this has potential of becoming a useful tool for quicker and safer decision-making. Simultaneously, the on-screen information is already extensive to the point where visual cues must be kept
discrete, as not to interfere with other information and overlapping the screen [6].

**THEORY & RELATED RESEARCH**

**Mental Workload**

For fighter controllers, a large emphasis in the profession is on abilities to handle a high workload and stressful environments [4]. The concept of workload has been widely discussed in aviation, despite lack of consensus on its definition [1]. The mental workload is by De Waard [8] defined as “a relative concept; it is the ratio of demand to allocated resources”. Other interpretations of mental workload emphasize that it is a multidimensional concept where task load, performance and information processing approaches has largely been utilized [1]. The mental workload is not only related to the complexity of the tasks at hand, but also the individuals’ reaction to the tasks, meaning it is not only the actual external input load, but the individual’s experience of the situation [8]. Mental workload can thus be different for individuals as well as situation, this makes it hard to define and measure objectively.

**Current Systems**

Information on fighter controllers, their systems as well as tasks, is limited. Even training for future fighter controllers is largely conducted without documentation [3,4]. The simulator systems at FLSC, are similar to the versions used in flight situations. Some of the most important differences are that the simulator system, has limited interaction possibilities, it shows information more precisely than an actual radar, and presents a smaller amount of information. This system is designed for the specific use of practicing tactical scenarios with pilots at FLSC, not for training the controllers cognitive abilities.

The radar view is a top down map view, with icons symbolizing airplanes along with an identification tag next to it, stating id, altitude, relative position and additional information can be shown as preferred. The view on the radar screen, is not static, meaning, views of one user does not necessarily correspond to another. During their education, the future fighter controller is encouraged to experiment with the available information, as to find a layout suitable to them, in turn, this means some information may go unnoticed [4].

**Visualization**

There have been numerous publications on visualizations as an aid in decision making and visualization methods differ largely depending on intended area of use. In the specific field of fighter control, most important is that the visualizations aid the user in retrieving information through a decreased cognitive load [6,20]. Specifically, delimiting the number of possible conclusions that can be drawn as well as attracting attention to critical areas on the display [3,20]. Computational offloading is the approach for decreasing the mental load through external representation. This means, the external representation functions as support, by efficiently representing information for immediate perceptual recognition, and thus less cognitive load is required [21]. To fit the scope of this study, the starting point has been limited to Wolfe & Horowitz [24] theories on visual aspects that stand out in identification tasks. Important factors for drawing attention are summarized as traits that stand out, specifically; color, size and movement are all regarded as pre-attentive [24]. In additional support, Garlandini & Fabrikant [11] conclude sizes to be the most efficient trait in geographic visualization, followed by color hue and value.

As the radar view of a fighter controller is a top-down map view, it could be of interest to consider the area of geographic visualizations. Attempts at evaluating printed thematic maps in tasks of understanding a three-dimensional space show that a preferred map type did not necessarily correspond to the highest performing one [7]. A user’s personal preference does not seem to be sufficient for evaluating maps where three-dimensional understanding is needed. This underlines the difficulties in designing maps as well as in evaluating them. Other studies show relatable results; maps that look more realistic did not necessarily provide better results for a given task. Instead, a well-designed yet unrealistic version was proven more efficient [23]. To further emphasize the nature of geographic visualizations, Nöllenburg’s [19] quote “we are not always logical in visual thinking” is suitable.

**System Evaluation**

For the purpose of appraising the systems in this study, the term affordance needs to be defined. The concept was initially created to demonstrate an animal’s relation to its environment, then, a decade later, it was brought into the emerging area of HCI where it was popularized. Nonetheless, it was not explicitly redefined, hence, it is still used somewhat arbitrarily [12,22]. The opinions on the concept itself differs and Still & Dark [22] find that it lacks specific meaning, without being redefined. In this paper, affordances are inspired by the efforts of Norman [16] and Kaptelinin & Nardi’s [12]; affordances are not learned, artificial behavior, instead, an application’s affordance is defined by its potential in aiding a user in its task, it should be perceived immediately, it is intuitive, and may be different for different individuals.

Evaluating a visualization is not a trivial task. Research has been conducted regarding how this should be approached. Both benchmark tests and qualitative interviews can be used to show insight on a visualization [17]. However, trivial benchmark tasks are often too simplified to provide a meaningful understanding of a complicated task, as they lack synergy and should only be used as complements to qualitative evaluations [17]. Heuristic evaluation, on the other hand provide opportunities to evaluate systems and identify usability problems using only a small number of participants but may instead lack proof on efficiency [15].

**Related Research**

**Civil Aviation**

As civil air traffic controllers’ tasks and tools are similar to the military counterpart, studies in the civil area are highly
relatable to the military field. The need to process large amounts of rapidly changing quantitative data from multiple sources is a main challenge [9]. Relatable attempts at decreasing the cognitive load through visualizing height includes a perspective view for pilots in free flight [6] as well as heat map alternatives for controllers [27]. Despite very different solutions, the common denominator is to draw attention to problematic areas to help the user discover possible problems quicker. Results have varied, and more experienced users have been found to be less likely to accept new alternatives [6].

Military Visualizations
Attempts at visualizing military information, not flight specific, often presses the difficulty with a continuously, and often rapidly, changing battlefield [18,25,26]. As with visualizations in civil aviation, attempts in military visualization aim at showing problematic areas and helping command in decision making. Attempts at showing information over multiple points in time is an experimental approach that has been previously researched [18,26]. More orthodox visual cues, with size varying depending on a forces strength has also been explored, with positive results [25].

Research Question
To summarize, this field is problematic mainly due to the large amounts of data and quick decisions required. The work environment is stressful and requires constant communication decision making and a great situational awareness. The interactive radar systems display information in an inefficient manner and could be improved. Visualization has previously shown to have potential in decreasing cognitive load and might thus be useful to incorporate further in the systems for this specific user group.

Attempts at decreasing the mental workload in similar fields have common problems of adding more information to an area already overflowing with information, and often lack proven efficiency. This paper aimed to investigate if the current altitude information in the simulators interactive radar systems could be improved as to increase user experience and efficiency. This thesis poses the following research question:

What are the affordances and limitations of different design options for interactive visual representation of height on a two-dimensional radar screen, as measured by task performance, and user experience of fighter controllers in their task of reading and analyzing combat simulation?

METHOD
To evaluate the research question, successfully, the methodology consisted of multiple aspects, presented in detail in this section. Initially, observations of fighter controllers at FLSC were conducted for a general understanding of their duties and needs. Furthermore, a prototype was created, and pilot tests carried out. The prototype utilized experimental and control conditions which were then evaluated in a user study, consisting of two main parts, heuristic evaluation and benchmark tests.

Visits and Observations
As documentation on fighter controllers’ working environment and the systems in use is scarce, the pre-study literature review was supplemented with visits at the FLSC simulator hall. Observations of fighter controllers in simulator training were conducted. Along with this, opportunities for brief discussions with two fighter controllers, one Swedish and one foreign, regarding their tasks and systems. As no electronic recording devices are permitted in the FLSC simulator hall, these were documented in writing.

Prototypes
To determine the possibilities and problems with different visualizations of the crucial altitude information, prototypes were created. Development of the prototype was conducted in the JavaScript library D3 (version 4). Multiple visualizations were designed, based on Wolfe & Horowitz [24] and Garlandini & Fabrikan’t’s [11] theories about visual perception, namely stand out traits being movement, color and size. In consultation with former fighter controllers at FLSC, two visualizations were considered more interesting for further development and evaluation in user studies. These being made the experimental conditions. These were chosen as they were considered potentially useful without interfering largely with the existing system, and as they were largely varying in character. A new interaction possibility was incorporated as this also has potential for efficient computational offloading. Additionally, as the simulator systems could not be utilized for this specific user study, a control condition meant to mimic the existing system, was created. The purpose of this was to assess the new visualizations benefits and shortcomings compared to the existing version.

Pilot Study
A pilot study with three participants was conducted to identify and remediate shortcomings ahead of the user study. All participants in the pilot test had academic merits in human computer interaction, however none familiar with flight simulators, or fighter control. The pilot study resulted in adding on-screen task information for the benchmark tests, fewer scenarios in the benchmark tests and an increase of questions in the finalizing form.

User Study
The three chosen conditions were ultimately evaluated in a user study, with five Swedish fighter controllers as expert users. Participants were four males, one female, with varying levels of experience, as shown in Figure 1. As Swedish fighter controllers are a homogenous group, where all users have the same education and similar background, it is easy to generalize within the group. Thus, the group of expert users participating in this user study well represent the intended target group. All tests took place at the FOI in Kista,
Stockholm, where the fighter controllers were practicing tactical scenarios at the FLSC simulator facility. The tests took place in one secluded office, without disturbance from outside factors. The study consisted of two main parts, qualitative and quantitative, designed to complement the other. The qualitative aimed more towards user experience and the qualitative to estimate task efficiency. The participants were recorded with audio, all data was handled anonymously, and consent forms were signed.

<table>
<thead>
<tr>
<th>Participant</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
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<td>Years of experience</td>
<td>&gt;10</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>&lt;1</td>
</tr>
</tbody>
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Figure 1: Showing the participants years of work experience, as a fighter controller.

Semi-structured Interviews
The initial part of the study consisted of heuristic evaluation and semi-structured interviews, based on Nielsen’s [14] approaches, showing efficiency only with a small number of participants. The participants got a chance to get acquainted with the visualizations, interacting with them freely, whilst discussing impressions and opinions on the proposed prototypes as well as how they compare to the current systems, which the participants are accustomed to. The semi-structured interviews lasted approximately 25-40 minutes and all covered topics on the need for development of the current system, the visualizations’ potentials, shortcomings and the idea of having interactivity for height relations. Further, understandability and intuitiveness of the visualizations, as well as shortcomings in the control condition, meaning issues in mimicking the original system, were covered. Multiple participants spent additional time, after the main topics were covered, to freely discuss and explain their job, experiences and thoughts on the future, showing interest in aiding the study’s purpose and appreciation to the interest shown in their tasks.

Benchmark Tests
The heuristic evaluation was followed by benchmark tests, as proposed by North [17], the benchmark tests function as complement to the qualitative part of the study. In the benchmark tests, the participants were given simple tasks - to quickly identify and sort one or multiple on-screen objects depending on their altitude. In this part, the altitude of the on-screen object was shown numerically in the control condition, as the controllers are used to. For the experimental conditions, participants were to sort only using visual cues. The tests were conducted identically for each of the three conditions, but with a randomized order. The benchmark tests logged decision time as well as accuracy of mouse clicks on screen. Accuracy was measured binary for tasks around finding one particular object, in sorting tasks, results could instead be awarded as half point or two out of three, for example.

After the benchmark tests, the participants completed a short questionnaire, based on the Post-Study System Usability Questionnaire (PSSUQ) [13], due to its generalizability and usefulness in competitive evaluations. 7-graded Likert-scales, were used, covering topics on perceived usefulness of the visualizations, confidence in decision making in the benchmark tests and preferred version.

RESULTS
The prototyping of visualizations generated two versions for evaluation in user studies. This user study was conducted in March and April at FOI in Kista, Stockholm. All participants completed the study successfully. All quotes have been translated from Swedish.

Prototype
Two methods of visualizing altitude were considered potentially beneficial. These utilized different approaches of adding information to the radar’s existing symbol for airplane. The visualizations were incorporated in a prototype system. This system displayed typical practice scenarios for fighter controllers. The system included the opportunity to display the altitude information in three different ways, two experimental conditions, displaying altitude as new visual cues, and one control condition, mimicking the original version.

Experimental condition A (Figure 2) utilizes color coordination, with opacity varying, as a mean of representing height with iconography, for the purpose of drawing attention to an intended area on screen. This means, highlighting the jets on the highest altitude as these are, per default, in an advantageous position. The lowest altitude would be mapped to opacity zero and the highest to opacity 1, the mapping range was linear.

Figure 2: Experimental condition A, using color coordination

Experimental condition B (Figure 3) uses different sizes, intended to create an intuitive illusion of perspective, a
perceived depth, and thus decrease the cognitive load. The jets on higher altitude are thus larger. As in Experimental condition A, mapping was linear. These approaches share similar fundamental ideas as previously mentioned attempts in civil air traffic visualizations [6,27]. This visual was not created to add realism, but instead encouraging abstraction, which can make geographic visualizations more efficient [23]. One example of this is the way metro systems utilizes abstract maps to serve a specific purpose where realism would make use more difficult.

For the user study, these experimental conditions were put against a control condition, a mimicking of the original version (Figure 4), where altitude is strictly represented as absolute numerical values. This is incorporating the important aspects from the current simulator systems which were not accessed for this study.

To investigate the advantages of added interactivity in these systems, the possibility of locking on to one specific object was implemented in the prototype. From this, the relative altitude to the other on-screen objects was shown. This, due to the high importance of relative altitude between jets and its potential in aiding the user in constructing their mental image.

Semi-structured Interviews
In this section, the results of the qualitative interviews are presented. This section is divided into a number of subheadings, covering the main topics of the interviews, and highlighting noteworthy results in each.

General Sentiment to Added Visualization
When first presented with the notion of added visual cues, participants in the user study expressed varying reactions. Everyone was able to acknowledge both pros and cons with altitude visualizations, however two of the participants did express a clear reluctance to the general concept.

The positive opinions to the idea were based largely on the lack of user centered design in the current systems. One example, as stated by Participant 4: “focus seem to be on ‘only’ getting the technology to work, not how it is presented”. Others simply noted that almost all information is, in some way, represented visually, except for the ‘extremely important’ height information. Participant 2: “It is the only important aspect that is not shown visually in any way /.../ the visual (interface) does not have to solve all problems, but they could ease”.

The main issue identified by participants was in regard to the problem of cluttering, a problem commonly mentioned in related studies and introductory study visits. For example, Participant 1 stated: “there is actually already too much visual information (in the existing system) to successfully add more” and Participant 3: “I want as little information on screen as possible, I think this applies to everyone”. Additionally, participants expressed that they get the full mental image from the current numerical information and find it efficient enough. Participant 5: “You learn where to look, then it is really quick /.../ The existing labels gives the image required”. Albeit, this is a skill set that requires practice to become efficient, which is acknowledged by Participant 4: “visual cues could have been good, when I was new, now I don’t think it would”.

Experimental Condition A - Color
According to the participants themselves, condition A, using color coordination, was easy to understand and use. Yet, there were many concerns on how it would function if incorporated in actual flight systems. One of the five participants expressed that the color should be the opposite, darker indicating higher.

An advantage mentioned by participants was that the visualization made some objects stand out, especially the ones on a particularly high altitude. The main problem expressed by participants was that there is already an important color coordination. This is not an issue in the simulators, but in the in-flight system this is heavily used. Concerns were raised regarding that it may interfere with the surrounding colors and possibly cause confusion, especially
in stressful situations. As described by Participant 3: “I am personally against adding colors more than we already have /.../ Colors convey what I am allowed to do /.../ there may be a conflict”.

Experimental Condition B - Perspective
The perspective view was regarded as easy to understand, by all participants. There was also a consensus among participants that this approach was more intuitive than using colors. Participant 2 described it as: “like sitting above and that gives a feeling of distance”. Participant 1 expressed that this version “visualizes the process that I do, or believe I do, in my mind”. On the other hand, there were concerns related also to this visualization. It was brought up that large objects may become too predominant and thus make lower, and thus smaller, objects harder to detect.

Interaction for Relative Height
The concept of using interaction to set a target altitude, and visualizing relative height was deemed as unnecessary by all the participants. There was no difficulty in understanding the idea or using the interaction, however it did not provide new insight to the user. As stated by Participant 1: “it is likely useful somewhere, but I do not know where”. It was explained that in communication with pilots, the absolute value is always communicated, and therefore relative height would complicate the communication and may cause confusion. Multiple participants described that it is the pilot’s responsibility to position themselves in an advantageous position, and not something the fighter controllers is particularly concerned with.

Usefulness and Improvements
Related studies have argued around the level of experience being a factor when proposing similar changes in this field [6]. Also, in this user study, the two most experienced fighter controllers, each having more than seven years of experience, were reluctant to the initial idea of adding visual information. Two participants had no more than one year of experience working as fighter controller, these were not unconditionally positive to the idea, but had generally a more positive view on changes. They both stated that the more experienced users likely would object. The two participants who had difficulties seeing this concept as useful to themselves considered other groups who could benefit. Participant 1, who had the most experience, speculated that: “it could be useful for other positions, higher in command lines /.../ they use big screens to get overview, I think this (visualization) is better suited there.”

There were a few suggestions by participants on how the altitude visualizations could be improved. One common opinion was that different altitude levels could be used when using visual cues. This meaning, not a dynamically changing scale, instead showing objects on a particular altitude in a specific way. Closely related to this were suggestions that only certain objects should be highlighted. This being objects on unusually high or low level, or ones changing altitude very quickly, as participants found these behaviors especially interesting to note and should not go unnoticed. No alternatives to the proposed visual cues were suggested. Two participants in the study suggested that it would be of interest to improve the identification tags, as to make altitude more easily understood without adding visuals.

Benchmark Tests
The following section presents the quantitative results found. With only five participants it should be noted that there can be no definite conclusion drawn from benchmark tests alone, instead they are meant as a complement to the heuristic evaluation.

Accuracy and Reaction Time
To get a general overview of the efficiency of the different conditions, Figure 5 shows the respondents reaction times along the X-axis as well as accuracy, on Y-axis. This meaning, the top left corner is the most desirable location in the graph, as this indicates high accuracy and low reaction time. For most participants, the control condition, does provide the highest accuracy, but also requires longer reaction times.

![Figure 5: Distribution of respondents’ average reaction time and accuracy](image)

The reaction times alone are shown in Figure 6 showing four participants displaying similar results, where one particularly stands out. Participant 5 outperformed the versions with visual cues with reaction times well below her average. Participant 5 expressed the control condition to be easier, simply because “I’m used to it /.../ you know where to look”.

![Figure 5: Distribution of respondents’ average reaction time and accuracy](image)
As average reaction times vary largely among participants, the absolute values may lack some information. Instead, Figure 7 displays the relative reaction times, in comparison to one’s own average on the X-axis. The Y-axis displays the accuracy in terms of average accuracy for one individual. This meaning, the center point (0,0) equals the average value for each person, and the axis displays the relation to the average in percent. This chart further underlines that all participants performed their best results on accuracy using the control condition, always performing above average. Reaction time is slightly more spread out, but for the majority, visualizations are quicker which is an advantage.

For the majority, reading the numbers individually makes for slower reaction times than the visual cues. Three participants expressed that they could feel their response time decrease, and Participant 1, who was reluctant to visual information, felt: “surprised it was so much quicker”. The results of the two experimental conditions are almost identical in terms of both accuracy and speed, no distinction can be drawn on their respective effectiveness.

Preference and Performance

In the finalizing questionnaire, participants were asked to rate their certainty in their decisions, during the aforementioned benchmark tests, on a 7-graded Likert scale. These ratings are presented in Figure 8, with the average values separately, to the right. The user’s perceived confidence in their decisions were almost identical when using the two experimental conditions. The participants were slightly more confident using the control condition, and no participant rated this lower than any experimental condition. Noteworthy is that three participants felt more certain in their decisions using the visualization with which they actually performed worse in terms of accuracy with.

DISCUSSION

The purpose of this study was to examine the affordances and limitations of different altitude visualizations for aiding fighter controllers in their current tasks, at the simulator facilities at FLSC. Here, affordances consist of the potential in aiding a user in his task, intuitiveness and immediate perception. As mentioned, the fighter controllers’ tasks are much more complex than simply identifying and organizing on screen objects. The main benefit for this user group would be a decreased cognitive load, for pre-attentive understanding. The high mental workload origins in the multitude of simultaneous complicated tasks, including communication and decision making under extreme time constraints. The visual aid would benefit only a small part of the controller’s work environment. Visualizing for a decreased cognitive load has in this study been attempted in

Figure 6: Average reaction time for the three visualizations, sorted by respondent.

Figure 7: Respondents reaction time and accuracy in percentage relation to their own average.

Figure 8: Participants perceived confidence in their decision making, during benchmark tests.
two different versions. The first version A, used color and version B, aimed to show altitude through varying sizes, as to imitate perspective. The main challenge has consisted largely of implementing additional visual information to a setting already overflowing with visual cues.

To successfully answer the research question, finding the affordances and limitations of different visualizations, both in terms of performance and user experience, one must look at common traits in visualization contra numerical representation, as well as each visualizations potential. All but one participant performed quicker decisions using visualizations and everyone had a greater level of accuracy when using absolute numerical values. Among the visualizations no significant difference in performance can be shown. On the other hand, all but one participant responded that they preferred the perspective view over the color coordination and described this as more intuitive as well as less likely to interfere with other on-screen information. Interactivity to show relative altitude was not considered beneficial to any participant. In these results, there is no correlation found between performance and preference.

**Potential Benefits**

Regarding the fundamental question whether visualizations hold benefits on the current numerical version, this study lacks definite proof. Even if quicker decision time among visualizations would be statistically reliable, it would come at the cost of a higher percentage of wrong answers. It is not possible to determine at what cost accuracy should be weighed against decision time in this study, and these tradeoffs are a common problem when using benchmark tests [17]. It is important to acknowledge this issue, yet it reaches beyond the scope of this thesis.

Some issues around the incorporation of relative altitude may have had to do with the mapping of the visual information. As mapping was constructed the chosen jet was set as a target on the lower end of the spectrum, as to display objects at a higher altitude more clearly. This did however have a negative effect that some objects changed appearance when chosen. This could be confusing to the user and serve as unintuitive in a stressful situation and may even mean conclusion based on misconception. For further understanding of potential benefits, more efficient means of mapping should be investigated.

Considering the user experience, visualizations should be regarded as potentially beneficial, some even expressing surprise over how much quicker they performed using only visuals. However, all participants in this study expressed, to some extent, concern with adding more visual information. There were frequent mentions of possible problems, for both experimental conditions, particularly condition A, using color. This may indicate that the concept of visualizing height could be described as a zero-sum game. Meaning, improvements in some areas may always have a negative impact on another, thus becoming a delicate balancing act.

Other studies on fighter control and civil air traffic control have also reached relatable results, some even concluding that adding visual information may not be a desired approach: “Designing visualizations in this area is often an exercise in choosing what not to draw, rather than what to draw” [6]. In military visualizations utilizing color hue has been used for the purpose of identification and color opacity to convey strength, which has been successfully implemented [25]. Different color hue for different objects could potentially have been applied in this concept and thus avoided the commonly mentioned issues of possible interference.

**Experience**

The users’ level of experience is a factor that has been highlighted in similar studies; there seem to be a stronger reluctance from more experienced users to implement new visualization [6]. This study points in the same direction. It is understandably more difficult to see a need for change in a system one is accustomed to. This makes it easy to dismiss these views as mere reluctance to change. It may however also indicate that there is actually a very small need for certain users. As some participants suggested, it may even be more suitable for other positions, higher in command lines. There, less detail is required and more of a general overview is beneficial, often for the purpose of having multiple users simultaneously considering one screen. Relatable studies, proposing visual cues in military use, have focused on such positions, [5,18,25,26] giving additional substance to these suggestions.

Alternatively, visualizations are perhaps not beneficial to experienced fighter controllers, instead showing potential as a tool for novices. After all, participants with the least amount of experience were also the most positive and two noted that it could have been beneficial at an earlier stage of their career. As training for fighter controller largely consists of learning how to use the systems and value information, efficiency will be learnt with training [4]. Adding options for visual cues may have a positive impact earlier in the learning process. As, Scaife & Rogers [21], discuss around graphical representation, one main purpose for this may exist in aiding the learning process. Additionally, the statement made by Participant 1; that it visualizes what he believes to do mentally, further underlines that it may provide more insight for someone who is not accustomed to the system. This idea motivates further studies, specifically designed for this purpose.

The sole lesson one confidently can draw from the differing opinions on usefulness is that it would create unnecessary complications to force users to adopt a change in the system. As noted, fighter controllers have the ability to, to some extent, choose what information they want shown on their screen. Thus, a recommended approach would include having visual cues as optional for the user. The fact that not all information needs to be shown by every user, makes
implementation and transition easier for all users, regardless of level of experience.

One may consider this study in an even larger perspective. Albeit somewhat speculative, future development in flight technology may have consequences on fighter controllers as well as civil air traffic controllers. With an ever-increasing amount of air traffic, there is a risk of even higher demands on the mental workload. New technology, for example drones, operating without pilots, may further this development. It is possible that despite skepticism from more experienced fighter controllers, their systems may become insufficient. This would mean a need for change in the future, possibly larger than this attempt has suggested.

Preferences
Regarding the fact that experimental condition B was the preferred version, by four out of five participants, it is somewhat problematic that this cannot be supported in tests on efficiency. There is no correlation between preferred version and higher performance in this, nor in related, studies [7]. Similar studies have proven both approaches of visualization to be potentially useful in air traffic [6,27]. Thus, arbitrary iconography may still be an equally high performing approach as more realistic maps have proven not to perform better than well designed, yet unrealistic, maps [23]. When considering the two visualizations’ respective affordances, condition B displays a clear advantage as also being the more intuitive version.

In Garlandini & Fabrikant’s study [11], the visual variable size was considered the most efficient in 2D map visualizations, meaning the users’ preferences in this thesis has some support. However, it must be noted that the preconditions and ultimate aim of these two studies are undeniably different. Mainly as Garlandini & Fabrikant’s [11] investigates strictly classical maps, no height included, displaying no problems in cluttering, blocking or aims to make use of perspective.

Method Criticism
To be able to draw any definite conclusions from quantitative tests alone, a larger number of participants would have been required. To draw conclusions on the heuristic evaluation, a small number of participants provide the fundamental understanding as intended. However, greater numbers and fighter controllers from a wider range of backgrounds, would provide insight and possibilities to generalize within the group. Additionally, as Nielsen & Molich [15] mention, the method is biased by the initial mindset of the participants, which this study also indicates. Moreover, this study has presented users with one system they are already accustomed to, whereas the two alternative variations are new to the participants. This previous experience likely means some level of bias.

One main concern in the study conducted is the lack of synergy. As a main difficulty in a fighter controller’s duties is the heavy load of information, testing visualizations without this aspect leaves many questions unanswered. As North [17] notes, many benchmark tests are too simplified to give a meaningful understanding of a complicated task, as they lack synergy. Thus, more complicated, simultaneous tasks, as well as distractions, could have benefitted the benchmark tests and increased viability. On the other hand, this is mainly a problem in the systems used in flight - not in simulators, these have not been accessed in this study. The study would nonetheless have benefitted from an increase in mental workload required from the participant. Adding an additional task would increase understanding of the potential in visualizing this numerical information. The additional tasks could have been created arbitrarily, such as spelling or mathematical problems, meaning not directly related to the fighter controller tasks, but simply.

As stated, visualizations would never function as to replace numerical labels, but instead be used as a complement. In the benchmark tests, the labels were removed for the experimental conditions, likely having a direct effect on both decreased reaction time as well as lower accuracy. If labels were shown along visualizations, both accuracy and reaction time would likely increase. Differences in results could therefore be even smaller. Ultimately this choice of benchmark test also means that the idea for future system have not been tested, only the visualizations themselves.

Future Research
The lack of consensus on the usefulness of visualizations in this context underlines the need for future research. No unanimity around incorporating a height visualization does not imply the concept to be unnecessary but simply points to the number of challenges it faces. As condition B, displays a greater user experience among the participants, yet cannot be proven more efficient, further studies must be encouraged. Additionally, the concept of perspective, contra color coordination can be discussed in other contexts of geographic visualization.

Participants found the relative altitude to be beyond their interest, despite the fact that it is very important in air combat. This is especially noteworthy in the light of Participant 1’s statement that it is the pilot’s responsibility to position themselves advantageously. This indicates a surprising division between the two roles. One would assume that the controller also would feel responsible for aiding the pilot to a good position. It was made clear from this participant that they are not too concerned with this, despite that it could be beneficial to the pilot. Here, it would be interesting to consider the pilot’s view of the situation and investigate whether this communication could be improved.

Additional research where visual cues are implemented in simulator training systems, would be suggested. Mainly, as there is limited opportunity to draw further conclusions on the usability in stand-alone benchmark tests. The lack of synergy in this study is predominant, and the next logical step for further research, should focus on incorporating this aspect. Further, adding more advanced measurements to
similar benchmark tests could increase understanding, for example eye-tracking, as to measure if the participants visual search pattern changes.

For further development of the visualizations, the idea of using altitude levels instead of dynamic shifts in the visual cues should be encouraged, as dynamic changes seem unpopular in this study. Using layers for visualizations would provide a general overview which according to users would be sufficient. Alternatively, only highlighting the icons portraying some specific behavior, being either an unusual altitude or a rapid altitude change, would help the user spot these occurrences quicker and is also an interesting approach.

CONCLUSION

There is potential for improvements of the current system of fighter controllers. The on-screen information is often cluttered, and users see potential for increased focus on user-friendliness. However, added visual information is also met with reluctance from the users. Difficulties in adding visual information to the fighter controllers screen is largely based on the great amount of information already shown, along with the user’s ability to already create the mental image needed. The two visualizations evaluated in this study had different starting points; one drawing attention to a certain area using color coordination, the other using a perspective view to perceive depth. Both variations aimed at aiding in pre-attentively identifying objects, and lower the cognitive load, increasing user experience and task-efficiency.

No visualization could be proven more efficient than the other, nor could a definite improvement to the current numerical version be determined. However, all participants expressed the perspective view as more intuitive, and four out of five preferred this version. It can therefore be regarded as somewhat successful, despite the lack of proof of a decreased cognitive load. Whether the color coordination manages to draw attention as intended is less clear as this cannot be determined from benchmark tests or interviews.

As affordance is considered by its potential in aiding a user in its task, its immediate perception, and intuitiveness there is a greater future potential for version B, using perspective. Both versions display potential in decreasing the mental workload, which is the main purpose in this area. Both systems were considered easy to understand, but the version B was somewhat easier to perceive immediately, as the colors could be inverted according to one participant. Main limitations, for both visual cues, is the cluttering when appending more information. This problem is more persistent when using color coordination, but also larger sizes may interfere. Changes to the system is met with reluctance and increased interaction lacks usability. However, as affordances may be different for different individuals, some ambivalence persists. The lack of definite conclusions encourages others to apply further research on the affordances and limitations of visualizations, and specifically using perspective views, for decreasing the cognitive load of fighter controllers.

REFERENCES

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