The Effect of Sensory Distractors on Search Task Performance in Augmented Reality

Paper ID:

ABSTRACT

This paper addresses how real-world distractors, both visual (e.g., optical flow), and non visual (auditory noise),can affect search performance in augmented reality displays. Distractors are commonly investigated in visual search task, yet, often are abstract (e.g., symbols) instead of mimicking real-world stimuli. Even more so, non-visual distractors are often disregarded. ...

role of stimuli in AR potential effect study + contributions

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 INTRODUCTION

In outdoor environments, Augmented Reality systems still face many challenges that limit their application [20]. While some issues may seem obvious – e.g., most head-worn devices cannot deal well with high brightness environments – the effect of other factors is not straightforward to identify. Over the years, studies have been published that looked specifically at label visibility and legibility factors such as colors or textures. Others have proposed techniques to optimize label placement based on environment condition, like color contrast and saliency. Generally, these studies and techniques help to improve view management systems, which are concerned with the appearance and ordering of (predominantly visual) information in augmented reality systems. As one of the contributions of this paper, we provide a comprehensive overview of relevant studies and systems with focus on visibility in view management systems.

Generally, view management stays challenging, often caused by the add-up of different factors associated with different steps in the ”perceptual pipeline”, e.g., the environment itself, the capturing of the environment, or the display device [37]. Most studies and view management techniques focused at improving visibility and legibility. However, results are often not framed in actual usage scenarios, that is, in frame of a real-word task performance in a non-controlled indoor or outdoor condition.

While the analysis of all possible factors that may affect performance, as well as the interaction between factors, is a daunting and perhaps impossible task, there are still many open issues that can be analysed. Each can pay tribute to improve view management. In this article, we extend previous work by looking at environment and task related issues that have been under-represented in past studies. In particular, we study the effect of optical flow, background text inferences, label eccentricity and secondary tasks on visibility and awareness (noticeability) of labels. We choose these issues as they often occur in outdoor conditions and extend previous work. For example, consider using a city information system while walking around a city. During walking we experience optical flow while passing by people, cars and stores, while the latter usually have some form of advertisement (background text). While we pass, new labels may appear, in varying areas of our field of view (eccentricity). Finally, while walking, we may need to concentrate on not bumping into people or objects while looking at the labels, hence, there often are two tasks involved. Certainly, other factors will also play a role, such as changing light conditions or reflections. However, as these factors are difficult to control or even simulate in a test environment, we choose to avoid these factors.

This paper addresses WHAT and HOW Structural approach to analyse a subset of issues actually tries to quantify ”outdoor conditions” to get a better grip on the range - though clearly the range is theoretically infinite! Also: analyse other useful factors? Research agenda?

1.1 Contributions

In summary, through this paper we provide following contributions:

- **Overview:** An overview of previous work on the study and optimization of visibility aspects in Augmented Reality view management systems based on environmental conditions, including a gap analysis.
- **Measure:** The performance and analysis of a range of outdoor measurements to characterize typical environmental conditions
- **Study:** A four-part user study addressing the effect of optical flow, background text, label eccentricity and secondary task on the visibility and awareness (noticeability) of labels through in a simulated environment, based on analysis of the typical outdoor conditions

A better understanding of these factors can help us to design improved view management techniques, while also informing interface designers about the limitations with current systems.

2 OVERVIEW: PERCEPTUAL ISSUES ASSOCIATED WITH OUTDOOR CONDITIONS

In this section, we will provide an overview of typical perceptual issues associated with augmenting information over outdoor environments. Generally, dealing with visibility issues is the task of the view management component being used in the AR system. Designing and optimizing the layout of augmentations has been the focus of research for quite some time [5]. Studies mainly focused on size and position issues of label placement [3, 5], depth-placed ordering [54, 55] and label appearance like foreground-background issues [24] or the legibility of text [17, 41]). In the following we will look more closely at perceptual issues, potential consequences of narrowing the FOV and studies that affect view management in outdoor conditions.

2.1 Perception in Augmented Reality

Perceptual issues can arise when observing and interpreting information from the generated virtual as well as the real world. A perceptual issue may not only be caused by the combination of the real world and embedded augmentation, but may also originate in the representation of the real world itself. As identified in [37], three types of perceptual issues tend to occur that relate to our visual perceptual system: scene distortions and abstraction, depth distortion and ordering, and visibility.

In this article we mainly deal with visual and non-visual issues that affect label visibility and noticeability. That is, our focus here is on processing visual information (visual augmentations) while potentially being affected by other visual and non-visual stimuli in the real world. While non-visual augmentations are also considered in literature, this fals outside the main focus of this article. To this extent, it is useful to take a closer look at how label visibility is affected by outdoor conditions. When we need to notice or search for a label, the ease with which this process can be performed is often affected by figure-ground perceptual mechanism that allow us to segment the label (figure) from the background, the outdoor environment over which the augmentations are placed (ground). Previous research with primates has shown that segmentation may lead to two distinct but associated processes: the enhancement of cortical activity associated to figure processing (foreground enhancement) and the suppression of ground-related cortical activity (background suppression) [53]. However, the neurophysiological processes underling scene segmentation, especially of natural imagery, is still under debate. Of interest is that some research points towards the possibility that segmentation is supported by processes prior to the engagement of attention and awareness [56]: many perception theories assume figure-ground segmentation operates pre-attentively to provide the perceptual units to which focal attention is allocated for further processing [33]. Attention will likely have an effect on the integration features, about which different theories exist, e.g., the traditional feature integration [64] or guided search theory [72] that support visual search.

During the process, boundary detection mechanisms detect changes in features, while a second mechanism fills regions by joining similar image elements [67]. With respect to AR background conditions, the so-called singleton detection mode may play an important role, as it a state in which spatial attention can prioritize objects that differ from other objects in certain feature dimensions. As such it is typically affected by perceptual issues such as color or brightness contrast [23] or shape factors [27]. This process has been associated with specific effects, such as the pop-out effect that has also been researched in the frame of user interface literature [26]. Features that differ from their surrounding ”distractors” are more easily processed, speeding up for example search processes [10]. Of particular interest is that words differ from symbols. Words have have both visual forms as strings of letters and semantic properties that symbols do not exhibit [40]. As such, text labels should likely be easier to segment from non-textual backgrounds, while text-on-text will not necessarily support this type of visual processing [9]. This process can be effected by eccentricity [10].

2.2 Noise, attentional mechanisms and concentration

Explain when / to what extend noise (auditory, visual, tactile) can affect visual perception, in particular visual search. Relate to attentional resources / concentration Mention explicitly cross-modal effects / papers

Describe here the concept of ”noise” and how it affects our task performance, e.g., by selective attention, etc. Also specifically cite audio noise papers!

Visual: Disparity plane issue - repeat what we found in TVCG 2020 and 2018 - when people focus on a label in the foreground, they may not be bothered by content in the background.

This may lead to the question: how close to the ”background” does a label need to be to cause a noise conflict?

Good overview of effects of noise on concentration, perception ... (see intro for related work) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4630540/

Visual search in noise: Revealing the influence of structural cues by gaze-contingent classification image analysis https://jov.arvojournals.org/article.aspx?articleid=2192970

Sound can suppress visual perception https://www.researchgate.net/publication/277476666$sound_{c}an_{s}uppress_{v}isual_{p}erception$

Acoustic noise improves visual perception and modulates occipital oscillatory states. https://www.researchgate.net/publication/258632344$_{A}coustic_{N}oise_{I}mproves_{V}isual_{}$

When sound affects vision: effects of auditory grouping on visual motion perception https://www.researchgate.net/publication/11996122$_{W}hen_{S}ound_{A}ffects_{V}ision_{E}ffe$

Effects of Background Music on Visual Lobe and Visual Search Performance https://www.researchgate.net/publication/318183257$_{E}ffects_{o}f_{B}ackground_{M}usic_{o}$

Sound enhances visual perception: Cross-modal effects of auditory organization on vision https://www.researchgate.net/publication/12283946$_{S}ound_{e}nhances_{v}isual_{p}erceptio$ $modal_{e}ffects_{o}f_{a}uditory_{o}rganization_{o}n_{v}ision$

Tactile stimulation can suppress visual perception https://www.researchgate.net/publication/259321226$_{T}actile_{s}timulation_{c}an_{s}uppres$

2.3 Studies and techniques reflection

Over time, augmented reality research has focused on studying specific perceptual issues, and designing novel view management techniques that improve for example the visibility of labels, e.g., to speed up visual search. Table X provides an overview of these studies and technical approaches. This article mainly looks into perceptual issues affecting visibility/legibility aspects of labels on top of the environment and the optimization there of, thus taking a more user-centered approach. As a result, the table focuses mainly on the ”environmental”, ”augmentation” and ”user” stages in the perceptual pipeline, instead of the more technical stages of ”capturing” and ”display device”. A detailed discussion of the pipeline is provided in [37] and will not be repeated here. When taking a closer look at the table, following statements can be made, including gaps in research. As can been seen in the table, the majority of previous work focused on either the effect of the environmental condition itself (e.g., brightness, color distribution, or texture), or optimizing label features or placement to optimize their visibility, and ease processing (e.g., in visual search).

Studies have mainly been performed on single issues. The majority of user studies and system implementations have focused on isolated perceptual issues. While relevant, these leaves ope the question how perceptual issues are potentially affecting each other, as proposed in [37]. While the authors refer to potential difficulties in assessing interactions between perceptual issues, it remains to be seen if user study results hold in uncontrolled conditions where multiple issues may affect visibility or legibility.

Studies have predominantly focused on visual factors. While more recently, audio and tactile view management methods have appeared, the majority of studies has focused on visual perception. Most perceptual studies have been focused on the effect of video background brightness, color, or texture, and drawing styles on the visibility of labels. In contrast, topics such as the effect of shape, motion or eccentricity on visibility have been underrepresented. This is mostly due to the fact that augmentations, till now, are predominantly of visual nature. Furthermore, the number of open issues associated with visual view management are still vast, forming an active field of research.

Studies have predominantly focused on text labels. In association with the mostly visual nature of view management, and the predominance of text labels, most systems and (associated) studies also focus on text labels.

Most studies are not performed in realistic outdoor conditions. With few exceptions, most studies have been performed under controlled conditions, not under real-world conditions. This is mostly caused by the limited brightness of head-worn devices, but also confounding factors such as varying brightness levels, reflections, or optical flow of background visuals. As such, most studies have been performed in labs, for example using video backgrounds, or simulated AR setups using either VR HMDs or large-wall displays. While cellphones meanwhile have screens that are bright enough for outdoor conditions, they have not been focused on frequently in recent years.

Studies mostly focused on visibility or legibility aspects. The majority of studies have focused on visibility (e.g., segmenting a label from a background based on texture or color contrast), and legibility (the readability of a text label). In direct relation, systems have been developed that optimize for visibility and legibility using, e.g., label placement optimization methods. In due course, also related issues have been assessed, e.g., depth perception.

Studies mostly used (simulated) narrow field of view displays. With the prevalence of commercial narrow FOV head-worn displays, most studies have been performed with displays of around 35 degrees diagonal. It remains to be see to what extent user study results are also applicable to wider FOV displays. While first studies on wide FOV displays (larger than 100 degree diagonal) have been performed, more research is needed.

Many system-oriented papers do not include extensive user studies. While a number of research systems have appeared that try to solve visual issues, many of the systems have not been validated in more elaborate studies, nor have most systems been used over longer periods of time. Therefore, it is not always easy to derive useful or applicable results from these papers.

Systems that optimize visibility or legibility aspects are hardly adopted. The majority of technical approaches has focused on optimizing label placement based on general visibility (e.g., avoiding labels occluding each other, and optimizing leader lines) or contrast with the video background, or affording extended visual capabilities such as "looking through" objects (e.g., transparency or x-ray vision). Doing so, most techniques only optimize for a sub-set of perceptual issues: no view management system is known that comprehensively covers the majority if perceptual issues. While systems have become available within a research-context to optimize view management, most systems - either within research or commercial context - are not widely adopted. In part, this may be due to higher processing requirements that cannot necessarily be handled by most computational units embedded in head-worn devices. While from a sensor perspective, requirements are mostly met with current head-worn devices, it remains to be seen when computational power catches up to allow for a wider adoption of real-time adaption of view management methods, except more simple label placement algorithms.

Studies often isolate factor analysis from actual task performance. Most studies mainly focus on assessing the previously mentioned perceptual issues, mainly being visibility and legibility. In due course, most experimental designs often exclude further factors, such as actual task performance. More recently, studies start to appear that assess visibility and legibility in task conditions that are more closely connected to real-world conditions. For example, studies have appeared that make use of a dual-task setup in which a main task is performed while reaction or search times in the secondary tasks are measured. This also brings forward the issue that perceptual issues are often regarded in isolation of cognitive issues, which does not necessarily reflect real-world task conditions.

There is hardly any quantification of what "outdoor conditions" entail. While most studies are performed in controlled (indoor) conditions, till now outdoor conditions have hardly been quantified. To this respect, it is difficult to address to what extent controlled experiments actually are representative for real-world conditions. While first studies have appeared that perform more thorough analyses of visual background conditions, extensive analyses of (or in) outdoor conditions will be necessary to make robust view management systems that can be used in real-world conditions. This publication performs a first step into this direction,by measuring a range of (representative) outdoor conditions, and studying to what extent certain conditions (optical flow and audio noise) may affect task performance.

Table 1: Overview of related work: Augmented Reality view management studies and systems focusing on perception and cognition aspects, label placement and appearance optimization. Work marked with a * was rather focused on a technical implementation, and/or at most had a smaller/pilot study.

Visual Aspect	Author	Focus
Brightness	Gabbard 2005 [19], 2006 [17], 2007 [18]	Effect of natural lighting on text legibility
	Grasset 2012 [24]	Label appearance modification (increasing contrast) based on background brightness *
	Livingston 2006 [43]	Effect of contrast (luminance) on visibility and color confusion
	Livingston 2009 [44]	Measurement of brightness in augmented reality displays, effect on contrast sensitivity in relation to acuity
	Orlosky 2013 [52]	Effect of moving labels to dark background locations to improve legibility
	Tanaka 2008 [36]	Label placement optimization based on background brightness *
Color	Bonanni 2005 [8]	Effect of exogenous cues (e.g. color overlay) on noticeability of overlay
	Gabbard 2007 [18]	Effect of text color on text legibility
	Garg 2011 [21]	Label / symbol color optimization based on background color *
	Kruijff 2019 [38]	Effect of color contrast with background and eccentricity on label noticeability and search time
	Livingston 2009 [44]	Measurement of color distortion in augmented reality displays, effect on color perception
Clutter	Lu 2014 [46]	Effect of environment clutter on label noticeability / search time
	Peterson 2008 [54]	Effect of label separation methods on visual clutter, legibility, spatial correlation
Depth	Gupta 2005 [25]	Effect of object distance and focus depth on human performance (speed, accuracy, comfort)
Eccentricity /	Kishishita 2014 [34]	Effect of eccentricity on search performance in dual-attention task
Field of view	Kruijff 2019 [38]	Effect of eccentricity on visibility and noticeability
	Trepkowski 2019 [65]	Effect of field of view on search performance
	ADD GRÜNEFELD F+C	Effect of out of view method on search task performance)
	ADD TVCG 2020 F+C	Effect of visual versus non-visual out of view method on search task performance)
Leader lines	Cmolik 2010 [68]	Leader line optimization based on crossing avoidance, distance, length and alignment *
	Fekete 1999 [16]	Resolving crossing leader lines *
	Grasset 2012 [24]	Adaptation of leader line color based on background color *
	Hartmann 2004 [28]	Optimization of leader lines for optimal object co-location *
Motion	Klein 2008 [35]	Image (post-)processing to improve seamlessness of augmentations and objects *
	Kruijff 2019 [38]	Effect of label movement with respect to movement in video background on label noticeability
	Okumura 2006 [51]	Effect of difference in image quality on seamlessness of augmentations and objects *
Occlusion	Berger 1997 [7]	Generating correct object occlusions of augmented objects through contour recognition *
	Kalkofen 2007 [30]	Usage of focus+context techniques to reveal occluded objects *
	Makita 2009 [49]	Label placement optimization avoiding object occlusion *
	Zhang 2009 [15]	Label placement optimization avoiding object occlusion *
Opacity /	Avery 2009 [2]	Usage of x-ray techniques to reveal occluded objects *
transparency	Bell 2001 [5]	Transparency modification as part of label management system *
also: occlusion	Elmqvist 2007 [14]	Effect of occlusion management based on dynamic transparency on search performance
	Kalkofen 2013 [31]	Effect of ghosting methods (transparency) on scene spatial assessment
	Looser 2004 [45]	Usage of magic lenses to reveal occluded information *
	Lu 2014 [46]	Effect of label opacity on label noticeability / search time
Placement	Azuma 2003 [3]	Effect of label placement algorithms / label overlap on reading speed
	Been 2006 [4]	Optimize label placement towards continuous zooming and panning actions *
	Bell 2000 [6], Bell 2001 [5]	Label placement strategies *
	Fekete 1999 [16]	Label alignment / stacking methods for improved legibility *
	Maass 2006 [47]	Label placement based on space optimization *
	Madsen 2016 [48]	Effect of temporal coherence and object vs image space label layout on task completion time
	Stein 2008 [61]	Technique focusing on temporal continuity during dynamic label placement *
	Tatzgern 2014 [62]	Label management technique in 3D object space to reduce label occlusion, maintain temporal coherence *
	Tatzgern 2016 [63]	Effect of hierarchical clustering on overview and search and recall tasks
	Vollick 2007 [70]	Parametric label placement based on example layouts *
	Zhang 2005 [15]	Resolving label occlusions through adaptive placement, label filtering and structured label searching *
Saliency	Grasset 2012 [24]	Label placement based on saliency calculation *
	Veas 2011 [69]	Effect of saliency modulation on awareness, attention, and memory
Shape	Lu 2014 [46]	Effect of label shape (square, circle, triangle) on label noticeability / search time
	Bonanni 2005 [8]	Effect of endogenous cues (e.g. arrows) on noticeability of label or overlay
Size	Lu 2014 [46]	Effect of label size on label noticeability / search time
Stereo	Peterson 2008 [55]	Effect of depth separation of superimposed labels (layers) on response time
Text	Debernardis 2014 [12]	Effect of label and text color on legibility
	Gabbard 2005 [19], 2006 [17], 2007 [18] [19]	Effect of drawing style / color on text legibility
	Gattullo 2015 [22]	Effect of text style, color coding, and illuminance on legibility
	Jankowski 2010 [29]	Effect of varying text drawing style, image polarity and background style on text legibility
	Renkewitz 2008 [58]	Effect of font color and font size optimization on text legibility
Texture /	Christensen 1995 [11]	Label placement optimization based on point features on a map or diagram so as to maximize legibility *
structure	Gabbard 2005 [19], 2006 [17], 2007 [18] [19]	Effect of background texture on text legibility
	Grasset 2012 [24]	Label placement optimization based on edge calculation *
	Leykin 2004 [42]	Pattern recognition approach to determine readability of text labels over textured background *
	Livingston 2006 [43]	Effect of visual frequency and orientation on visibility
	Orlosky 2013 [52]	Effect of moving labels to background locations with high uniformity on legibility
	Renkewitz 2006 [58]	Effect of background texture on text legibility
	Wieland 2009 [71]	Photometric adjustment of augmentations based on background shapes *

3 MEASURE: MEASURING OUTDOOR CONDITIONS

To assess outdoor conditions, we performed a number of measurements to assess the range of visual and non-visual environmental factors that may affect visibility and legibility of augmentations. To do so, we mounted several sensors on the head-worn display used for our experiments, a Microsoft Hololens 1. We choose to measure non-visual aspects next to visual as future view management systems may become multi-sensory, instead of visual only, as systems are appearing that, e.g., look into the usage of audio and tactile cues to extend visual-only view management systems [50]. Depending on the condition of the outside world, a different modality could be chosen. We made use of a Phidget Lux1000 light sensor (measuring up to 220KLUX), a Phidget 1104 vibration sensor (measuring g-forces), and a Phidget 1133 sound sensor (measuring up to 100db), which were connected to a Phidget VINT hub connected to a laptop computer. Signals were synced and plotted, and compared to video footage captured by a Pupil-Labs front facing camera (HD resolution) to assess if there were specific visual events related to peaks in environmental conditions. The video footage was also analysed in OpenCV (using Farneback's algorithm) to detect prevalent optical flow.

We had the opportunity to capture a range of different outdoor situations in a popular tourist city (New York) – a good example where a city information system could be deployed – to get a grasp on the variance in outdoor conditions. Table X provides an overview of the situations in relation to main environmental factors. As can be seen, we made use of a set of conditions to measure different aspects. The measurements consisted of around 3-5 Minute sequences, in which we contrasted brightness, optical flow, color distribution, audio noise and vibration. Doing so, we captured the following situations: a campus path (morning, afternoon, night), a street crossing, a quiet walk through Central park, a subway ride, and Times square, a crowded scene with a high number of artificial lights (morning and night).

3.1 Results

Here a page should come with "low" and "high" images as comparison between conditions: Brightness, Color, clutter, saliency, texture, optical flow: 4 in a row (pairs of original image/video frame + analysis) + couple of examples of variances in combined graphic (brightness, noise, vibration).

Noise fluctuations, Db Brightness fluctuations Optical flow fluctuations

Color distribution: TVCG paper method Optical flow: Farneback / opencv Clutter: feature congestion method [60] Saliency: Opencv saliency map

Reflect our analysed issues with the ones previously studied - which are prevalent, which are not?

4 STUDY: SIMULATED VR SEARCH

Summary here. explain what the study is, why we use VR (to exactly control conditions)

4.1 Research questions

RQ / What is the effect of visual and audio distractors ("noise") on search task performance?

4.2 Participants

4.3 Apparatus and Stimuli

HMD Unity Seated lab situation Calibration?

4.3.1 Noise Factors

Users performed the search task under varying noise conditions. To implement **visual noise** which approximately reflects real life conditions the user was presented a dynamic city scene by the HMD. In VR the user was positioned in front of a broad street and faced the opposite roadside. Cars and people moving from left to right and vice versa at different speeds were also included to generate varying levels of optical flow. Recurrent wind gusts that transported small (visible) particles were included to add more optical flow also at higher elevation levels. As occlusion issues may typically occur in real-world AR scenarios, targets and distractors in the VR scene could also briefly be occluded in parts by pedestrians and cars passing by closely in front of the user. For conditions without visual noise, the search task was performed in a 3D space with uniformly gray floor, walls and ceiling. The impression of depth was created by including a light source. A black background would have resulted in too much contrast to the search task stimuli and the user would have felt not present in a 3D space due to missing depth cues.

To include **auditory noise**, all noise-generating elements in the VR urban scene were provided with appropriate sounds (e.g. noise of engines, people talking and walking, wind, construction sites, ...). Auditory noise was provided to the user by a surround-sound leadspeaker worn around the neck of the user. The loudspeaker produced sounds at Db

So if the user is exposed to several noise factors at the same time, they match. Noise stimuli have been constructed in this way, because the present study focuses mainly on how real-world noise affects user interaction instead of addressing the effects of specific noise characteristics (e.g., comparing the impact of different frequencies, sound levels or exposure duration). Furthermore, when the impressions from the different sensory channels contradict each other cross-modal effects could result in an unwanted confounding influence on dependent measures. Apart from this, each noise factor can be switched on and off and thus be presented in combination with one or two other noise factors, but also alone or not at all.

4.3.2 Conjunction Search Task

We used a **conjunction search task** in this study as visual search in everyday life often requires looking for a specific combination of features. An exemplary target in an everyday conjunction visual search task could be a "blue car" while a single feature search would be a "car." A conjunction of features also occurs when working with picture labels (e.g., map icons that are associated with categories such as restaurants or tourism). For a fast and effective characterization a single feature is often not sufficient, so frequently two features are combined [66]. A common combination of features includes color and shape (e.g., a red color and a cross shape stands for a medical building) [66]. Picture labels can be particularly interesting in the context of AR and a narrow field of view as they use less display space compared to textual labels. In this study the target was also defined by a conjunction of color and shape and surrounded by distractors possessing one feature in common with the target.**Stimuli** that were used were red and green "X"s and "O"s (similar to [64,72]). That is, if the target was a green "X", then distractors were red "X"s and green "O"s, as each of them had one feature in common with the target. The target symbol and its position was randomly determined in each search. The search array always included one target and [red]XY distractors. They were evenly distributed in the user's horizontal field of vision at a 90 degree angle and in the vertical field of vision at a 78 degree angle. Colors and shapes were chosen for their low confusability as well as their symmetricality and similar brightness values. Colors were further chosen based on a color analysis of a static image of the city. In the course of the analysis four independent color clusters could be extracted which represent the dominant colors in the scene. Although there are various attempts in AR to adapt the color and contrast of augmented content depending on the background to improve visibility, it is not always possible or desired (e.g. when color is an essential attribute of the displayed content as for example in the case of a company logo). For this reason we decided to use colors for targets and distractors which are

Table 2: Overview of measurements: factors and situations with measurement conditions.

Factor	Situation / measurement
Brightness	Brightness variations natural light: campus path, partly under cover of trees (morning, afternoon, night) Bright artificial light with high contrasts: Downtown city centre (morning w. natural light, evening without natural light) Low artificial light: subway ride
Color contrast / distribution	High color contrast / large colour range / saturated colours: Downtown city centre (evening) Low color contrast / small colour range/ less saturated colours: Park walk (afternoon)
Clutter	Highly clutter environment: Times square (evening) Environment with low clutter:
Optical flow	Left-right optical flow: Downtown city centre, people/cars moving at street crossing (variance in optical flow) Forward optical flow: Downtown city centre, people moving at street in direction of travel (variance on optical flow)
Saliency	Highly salient environment: ...) Environment with low saliency:....
Texture	Highly textured environments, w. / without text, texture variance) Environments with more evenly distributed textures
Audio noise	Silent: park walk (afternoon) Noisy: Downtown city centre (evening)
Vibration	Vibration caused by self-motion: park walk (afternoon) Vibration caused by vehicle motion: Subway ride

not completely different from the dominant colors in the scene but also not too similar. Doing so, we aimed at creating an intermediate difficulty level regarding the potential interference of the visual background on search performance.

4.3.3 Simulation of the Narrow AR Field-of-View

For this, the FOV of the Microsoft HoloLens as current state-of-the-art AR headset is simulated in VR. This was achieved by placing a virtual display of about 35(diagonal) size 3cm in front of the user's eyes. This display used a semitransparent glass-like material in order to gain the impression of using an actual AR device (compare to [59]). Virtual augmentations are only visible for the user inside that simulated AR FOV

Target and distractor stimuli represent potential AR objects in this experiment. Therefore, we put a mask on the array of these visual stimuli so that they were visible only in a diagonal FOV of 52 degrees (HoloLens 2). To scan the whole search area with the narrowed FOV, participants had to move their head. The simulated augmented content was located on a cylindrical surface with a radius of 1.3 unity meters in the VR environment. The user was located at the center of the invisible cylinder. Consequently, stimuli at eye-level have an equal distance to the user. All the other stimuli were a little further away but the difference was barely noticeable. We decided to choose a cylindrical surface instead of a sphere because a sphere would result in an increased density of stimuli in the narrow upper and lower FOV of the user. This would affect visual search as more items would be visible at once within the narrow FOV and could be scanned faster. By using the cylindrical surface there is always the same number of stimuli in the upper and lower FOV. Simulating an AR environment represents one option to examine visual search with a narrow FOV independent of unexpected changes in the environment and factors which are not targeted (e.g., bad light conditions). In addition, the controlled laboratory setting can easily be replicated [1,32]. The validity of AR simulation has been assessed before [13, 39, 57].

4.4 Design and Procedure

The study employs a 2 x 2 factorial between-subjects design (resulting in 4 factor combinations) to study how visual and tactile noise with two levels (on/off) affect search performance (search time and hits) and visual search behavior (eye-tracking measures) in an AR conjunction search task. At the beginning of the study participants were welcomed at first and then informed orally and in writing on the purpose and procedure of the study. They filled out the consent form and were then seated on a chair in an upright sitting position. The experiment started with the participant facing straight ahead. The target to find was presented to the user at the beginning of each search in the center location of the HMD for 2 seconds. Then the search array appeared and was partly visible to the user in a FOV of 52, time measurement started. The target location was randomly determined with the only restriction that it was never visible within the FOV when the search started. The user could search through the array of stimuli by turning the head to move the FOV as stimuli were only visible in this area. Once the target was found and located within the FOV, the user pressed the trigger of the VIVE controller and scored a hit. During the main experiment there was no feedback on whether the target was actually present in the FOV or not. Independent from whether the user got a hit or an error, a new target to find was displayed and the next search started. Users performed the search task in 4 consecutive blocks. In each block 4 factor combinations were tested in randomized order and users searched for targets under one condition for 2 minutes until the next condition started. A short information on the upcoming noise factor was displayed before the condition changed to prepare the user Users were told to find as many targets as possible within the time limit. Before performing the main experiment users completed a 1-minute training session without noise to become familiar with the search task. During training they got feedback on whether the correct target was found or not. After having completed the study, users filled in a questionnaire on user demographics, the experience, usability and comfort. Overall, the experiment took around 45 minutes.

4.5 Results

5 Discussion

Discuss: - Effect of any type of filtering/attention behaviour (like used in the auditory system to filter out noise ("selective attention") - Effect of noise under different task conditions (what has been researched in the study, what could be done in further studies)

RQ1. .....

In conclusion, we showed that...

RQ2. .....

In conclusion, we showed that...

6 Conclusion and Future Work

Brief summary of results

How can view management be improved What studies could be done following this

Acknowledgments

The authors wish to thank A, B, and C. This work was supported in part by a grant from XYZ.

References

[1] J. Arthur, L. Prinzel, K. Shelton, L. Kramer, S. Williams, R. Bailey, and R. Norman. Design and testing of an unlimited field-of-regard synthetic vision head-worn display for commercial aircraft surface operations. In *Enhanced and Synthetic Vision 2007*, vol. 6559, p. 65590E. International Society for Optics and Photonics, 2007.

[2] B. Avery, C. Sandor, and B. H. Thomas. Improving spatial perception for augmented reality x-ray vision. In *2009 IEEE Virtual Reality Conference*, pp. 79–82, March 2009. doi: 10.1109/VR.2009.4811002

[3] R. Azuma and C. Furmanski. Evaluating label placement for augmented reality view management. In *Proceedings of the 2Nd IEEE/ACM International Symposium on Mixed and Augmented Reality*, ISMAR '03, pp. 66–. IEEE Computer Society, Washington, DC, USA, 2003.

[4] K. Been, E. Daiches, and C. Yap. Dynamic map labeling. *IEEE Transactions on Visualization and Computer Graphics*, 12(5):773–780, Sep. 2006. doi: 10.1109/TVCG.2006.136

[5] B. Bell, S. Feiner, and T. Höllerer. View management for virtual and augmented reality. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, UIST '01, pp. 101–110. ACM, New York, NY, USA, 2001.

[6] B. A. Bell and S. K. Feiner. Dynamic space management for user interfaces. In *Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology*, UIST '00, pp. 239–248. ACM, New York, NY, USA, 2000. doi: 10.1145/354401.354790

[7] M. . Berger. Resolving occlusion in augmented reality: a contour based approach without 3d reconstruction. In *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, pp. 91–96, June 1997. doi: 10.1109/CVPR.1997.609304

[8] L. Bonanni, C.-H. Lee, and T. Selker. Attention-based design of augmented reality interfaces. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, pp. 1228–1231. ACM, New York, NY, USA, 2005. doi: 10.1145/1056808.1056883

[9] M. Carrasco, D. Evert, I. Chang, and S. Katz. The eccentricity effect: Target eccentricity affects performance on conjunction searches. *Perception & Psychophysics*, 57(8):1241–1261, Nov 1995. doi: 10.3758/BF03208380

[10] M. Carrasco, T. McLean, S. Katz, and K. Frieder. Feature asymmetries in visual search: Effects of display duration, target eccentricity, orientation and spatial frequency. *Vision Research*, 38(3):347 – 374, 1998. doi: 10.1016/S0042-6989(97)00152-1

[11] J. Christensen, J. Marks, and S. Shieber. An empirical study of algorithms for point-feature label placement. *ACM Trans. Graph.*, 14(3):203–232, July 1995. doi: 10.1145/212332.212334

[12] S. Debernardis, M. Fiorentino, M. Gattullo, G. Monno, and A. Uva. Text readability in head-worn displays: Color and style optimization in video vs. optical see-through devices. *IEEE transactions on visualization and computer graphics*, 20:125–39, 01 2014. doi: 10.1109/TVCG.2013.86

[13] S. R. Ellis, F. Breant, B. Manges, R. Jacoby, and B. D. Adelstein. Factors influencing operator interaction with virtual objects viewed via head-mounted see-through displays: viewing conditions and rendering latency. In *Virtual Reality Annual International Symposium, 1997., IEEE 1997*, pp. 138–145. IEEE, 1997.

[14] N. Elmqvist, U. Assarsson, and P. Tsigas. Employing dynamic transparency for 3d occlusion management: Design issues and evaluation. In C. Baranauskas, P. Palanque, J. Abascal, and S. D. J. Barbosa, eds., *Human-Computer Interaction – INTERACT 2007*, pp. 532–545. Springer Berlin Heidelberg, Berlin, Heidelberg, 2007.

[15] Fan Zhang and Hanqiu Sun. Dynamic labeling management in virtual and augmented environments. In *Ninth International Conference on Computer Aided Design and Computer Graphics (CAD-CG'05)*, pp. 6 pp.–, Dec 2005. doi: 10.1109/CAD-CG.2005.36

[16] J.-D. Fekete and C. Plaisant. Excentric labeling: Dynamic neighborhood labeling for data visualization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '99, pp. 512–519. ACM, New York, NY, USA, 1999. doi: 10.1145/302979.303148

[17] J. Gabbard, E. Swan, II, and D. Hix. The effects of text drawing styles, background textures, and natural lighting on text legibility in outdoor augmented reality. *Presence: Teleoper. Virtual Environ.*, 15(1):16–32, Feb. 2006.

[18] J. L. Gabbard, J. E. Swan, D. Hix, S. Kim, and G. Fitch. Active text drawing styles for outdoor augmented reality: A user-based study and design implications. In *2007 IEEE Virtual Reality Conference*, pp. 35–42, March 2007. doi: 10.1109/VR.2007.352461

[19] J. L. Gabbard, J. E. Swan, D. Hix, R. S. Schulman, J. F. Lucas, and D. Gupta. An empirical user-based study of text drawing styles and outdoor background textures for augmented reality. *IEEE Proceedings. VR 2005. Virtual Reality, 2005.*, pp. 11–18, 2005.

[20] J. L. Gabbard and J. E. Swan II. Usability engineering for augmented reality: Employing user-based studies to inform design. *IEEE Transactions on Visualization and Computer Graphics*, 14(3):513–525, May 2008. doi: 10.1109/TVCG.2008.24

[21] S. Garg, K. Padalkar, and K. Mueller. Magic marker: A color analytics interface for image annotation. In G. Bebis, R. Boyle, B. Parvin, D. Koracin, S. Wang, K. Kyungnam, B. Benes, K. Moreland, C. Borst, S. DiVerdi, C. Yi-Jen, and J. Ming, eds., *Advances in Visual Computing*, pp. 629–640. Springer Berlin Heidelberg, Berlin, Heidelberg, 2011.

[22] M. Gattullo, A. E. Uva, M. Fiorentino, and J. L. Gabbard. Legibility in industrial ar: Text style, color coding, and illuminance. *IEEE Computer Graphics and Applications*, 35(2):52–61, Mar 2015. doi: 10.1109/MCG.2015.36

[23] E. Goldstein, G. Humphreys, M. Shiffrar, and W. Yost. *Blackwell Handbook of Sensation and Perception*. Blackwell Publishing Ltd, 2 2008. doi: 10.1002/9780470753477

[24] R. Grasset, T. Langlotz, D. Kalkofen, M. Tatzgern, and D. Schmalstieg. Image-driven view management for augmented reality browsers. In *Proceedings of the 2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, ISMAR '12, pp. 177–186. IEEE Computer Society, Washington, DC, USA, 2012.

[25] D. C. A. Gupta. An empirical study of the effects of context-switch, object distance, and focus depth on human performance in augmented reality. Virginia Polytechnic Institute and State University, 2004.

[26] C. Gutwin, A. Cockburn, and A. Coveney. Peripheral popout: The influence of visual angle and stimulus intensity on popout effects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, pp. 208–219. ACM, New York, NY, USA, 2017.

[27] A. M. Harris, O. Jacoby, R. W. Remington, S. L. Travis, and J. B. Mattingley. Taking a closer look at visual search: Just how feature-agnostic is singleton detection mode? *Attention, Perception, & Psychophysics*, 81(3):654–665, Apr 2019. doi: 10.3758/s13414-018-01642-y

[28] K. Hartmann, K. Ali, and T. Strothotte. Floating labels: Applying dynamic potential fields for label layout. In A. Butz, A. Krüger, and P. Olivier, eds., *Smart Graphics*, pp. 101–113. Springer Berlin Heidelberg, Berlin, Heidelberg, 2004.

[29] J. Jankowski, K. Samp, I. Irzynska, M. Jozwowicz, and S. Decker. Integrating text with video and 3d graphics: The effects of text drawing styles on text readability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1321–1330. ACM, 2010.

[30] D. Kalkofen, E. Mendez, and D. Schmalstieg. Interactive focus and context visualization for augmented reality. In *2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 191–201, Nov 2007. doi: 10.1109/ISMAR.2007.4538846

[31] D. Kalkofen, E. Veas, S. Zollmann, M. Steinberger, and D. Schmalstieg. Adaptive ghosted views for augmented reality. In *2013 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 1–9, Oct 2013. doi: 10.1109/ISMAR.2013.6671758

[32] K. Keller and H. Fuchs. Simulation-based design and rapid prototyping of a parallax-free, orthoscopic video see-through head-mounted display. In *Proceedings of the 4th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 28–31. IEEE Computer Society, 2005.

[33] R. Kimchi and M. A. Peterson. Figure-ground segmentation can occur

without attention. *Psychological Science*, 19(7):660–668, 2008. PMID: 18727781. doi: 10.1111/j.1467-9280.2008.02140.x

[34] N. Kishishita, K. Kiyokawa, J. Orlosky, T. Mashita, H. Takemura, and E. Kruijff. Analysing the effects of a wide field of view augmented reality display on search performance in divided attention tasks. In *Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on*, pp. 177–186. IEEE, 2014.

[35] G. Klein and D. Murray. Compositing for small cameras. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 57–60, Sep. 2008.

[36] Kohei Tanaka, Yasue Kishino, Masakazu Miyamae, Tsutomu Terada, and Shojiro Nishio. An information layout method for an optical see-through head mounted display focusing on the viewability. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 139–142, Sep. 2008. doi: 10.1109/ISMAR.2008.4637340

[37] E. Kruijff, E. S. II, and S. Feiner. Perceptual issues in augmented reality revisited. In *In Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 3–12. IEEE Computer Society, 2010.

[38] E. Kruijff, J. Orlosky, N. Kishishita, C. Trepkowski, and K. Kiyokawa. The influence of label design on search performance and noticeability in wide field of view augmented reality displays. *IEEE Transactions on Visualization and Computer Graphics*, pp. 1–1, 2018.

[39] C. Lee, S. Bonebrake, D. A. Bowman, and T. Höllerer. The role of latency in the validity of ar simulation. In *Virtual Reality Conference (VR), 2010 IEEE*, pp. 11–18. IEEE, 2010.

[40] L. Léger, J.-F. Rouet, C. Ros, and N. Vibert. Orthographic versus semantic matching in visual search for words within lists. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, 66(1):32, 2012.

[41] A. Leykin and M. Tuceryan. Automatic determination of text readability over textured backgrounds for augmented reality systems. In *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 224–230, Nov 2004.

[42] A. Leykin and M. Tuceryan. Automatic determination of text readability over textured backgrounds for augmented reality systems. In *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 224–230, Nov 2004. doi: 10.1109/ISMAR.2004.22

[43] M. A. Livingston. Quantification of visual capabilities using augmented reality displays. In *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 3–12, Oct 2006. doi: 10.1109/ISMAR.2006.297788

[44] M. A. Livingston, J. H. Barrow, and C. M. Sibley. Quantification of contrast sensitivity and color perception using head-worn augmented reality displays. In *2009 IEEE Virtual Reality Conference*, pp. 115–122, March 2009. doi: 10.1109/VR.2009.4811009

[45] J. Looser, M. Billinghurst, and A. Cockburn. Through the looking glass: The use of lenses as an interface tool for augmented reality interfaces. In *Proceedings of the 2Nd International Conference on Computer Graphics and Interactive Techniques in Australasia and South East Asia*, GRAPHITE '04, pp. 204–211. ACM, New York, NY, USA, 2004. doi: 10.1145/988834.988870

[46] W. Lu, H. B. Duh, S. Feiner, and Q. Zhao. Attributes of subtle cues for facilitating visual search in augmented reality. *IEEE Transactions on Visualization and Computer Graphics*, 20(3):404–412, March 2014. doi: 10.1109/TVCG.2013.241

[47] S. Maass and J. Döllner. Efficient view management for dynamic annotation placement in virtual landscapes. In A. Butz, B. Fisher, A. Krüger, and P. Olivier, eds., *Smart Graphics*, pp. 1–12. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

[48] J. B. Madsen, M. Tatzqern, C. B. Madsen, D. Schmalstieg, and D. Kalkofen. Temporal coherence strategies for augmented reality labeling. *IEEE Transactions on Visualization and Computer Graphics*, 22(4):1415–1423, April 2016. doi: 10.1109/TVCG.2016.2518318

[49] K. Makita, M. Kanbara, and N. Yokoya. View management of annotations for wearable augmented reality. In *2009 IEEE International Conference on Multimedia and Expo*, pp. 982–985, June 2009. doi: 10.1109/ICME.2009.5202661

[50] A. Marquardt, C. Trepkowski, T. D. Eibich, J. Maiero, and E. Kruijff. Non-visual cues for view management in narrow field of view augmented reality displays. In *2019 IEEE Symposium on Mixed and Augmented Reality (ISMAR)*, 2019.

[51] B. Okumura, M. Kanbara, and N. Yokoya. Augmented reality based on estimation of defocusing and motion blurring from captured images. In *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 219–225, Oct 2006. doi: 10.1109/ISMAR.2006.297817

[52] J. Orlosky, K. Kiyokawa, and H. Takemura. Dynamic text management for see-through wearable and heads-up display systems. In *IUI*, 2013.

[53] P. Papale, A. Leo, L. Cecchetti, G. Handjaras, K. Kay, P. Pietrini, and E. Ricciardi. Foreground enhancement and background suppression in human early visual system during passive perception of natural images. *bioRxiv*, 2017. doi: 10.1101/109496

[54] S. Peterson, M. Axholt, and S. Ellis. Label segregation by remapping stereoscopic depth in far-field augmented reality. In *Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, ISMAR '08, pp. 143–152. IEEE Computer Society, Washington, DC, USA, 2008.

[55] S. Peterson, M. Axholt, and S. Ellis. Managing visual clutter: A generalized technique for label segregation using stereoscopic disparity. In *IEEE Virtual Reality Conference 2008 (VR 2008), 8-12 March 2008, Reno, Nevada, USA, Proceedings*, pp. 169–176. IEEE Computer Society, 2008.

[56] B. C. Ralph, P. Seli, V. O. Cheng, G. J. Solman, and D. Smilek. Running the figure to the ground: Figure-ground segmentation during visual search. *Vision Research*, 97:65 – 73, 2014. doi: 10.1016/j.visres.2014.02.005

[57] D. Ren, T. Goldschwendt, Y. Chang, and T. Höllerer. Evaluating wide-field-of-view augmented reality with mixed reality simulation. In *Virtual Reality (VR), 2016 IEEE*, pp. 93–102. IEEE, 2016.

[58] H. Renkewitz, V. Kinder, M. Brandt, and T. Alexander. Optimal font size for head-mounted-displays in outdoor applications. In *2008 12th International Conference Information Visualisation*, pp. 503–508, July 2008.

[59] P. Renner and T. Pfeiffer. Attention guiding techniques using peripheral vision and eye tracking for feedback in augmented-reality-based assistance systems. In *2017 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 186–194, March 2017.

[60] R. Rosenholtz, Y. Li, and L. Nakano. Measuring visual clutter. *Journal of Vision*, 7(2):17–17, 08 2007. doi: 10.1167/7.2.17

[61] T. Stein and X. Décoret. Dynamic label placement for improved interactive exploration. In *Proceedings of the 6th International Symposium on Non-photorealistic Animation and Rendering*, NPAR '08, pp. 15–21. ACM, New York, NY, USA, 2008. doi: 10.1145/1377980.1377986

[62] M. Tatzgern, D. Kalkofen, R. Grasset, and D. Schmalstieg. Hedgehog labeling: View management techniques for external labels in 3d space. In *2014 IEEE Virtual Reality (VR)*, pp. 27–32, March 2014. doi: 10.1109/VR.2014.6802046

[63] M. Tatzgern, V. Orso, D. Kalkofen, G. Jacucci, L. Gamberini, and D. Schmalstieg. Adaptive information density for augmented reality displays. In *2016 IEEE Virtual Reality (VR)*, pp. 83–92, March 2016. doi: 10.1109/VR.2016.7504691

[64] A. M. Treisman and G. Gelade. A feature-integration theory of attention. *Cognitive psychology*, 12(1):97–136, 1980.

[65] C. Trepkowski, D. Eibich, J. Maiero, A. Marquardt, E. Kruijff, and S. Feiner. The effect of narrow field of view and information density on visual search performance in augmented reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 575–584, March 2019. doi: 10.1109/VR.2019.8798312

[66] C. Trepkowski, T. Eibich, J. Maiero, A. Marquardt, E. Kruijff, and S. Feiner. The effect of narrow field of view and information density on visual search performance in augmented reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2019.

[67] S. Ullman. Visual routines. *Cognition*, 18(1-3):97–159, 1984. doi: 10.1016/0010-0277(84)90023-4

[68] L. Čmolík and J. Bittner. Layout-aware optimization for interactive labeling of 3d models. *Comput. Graph.*, 34(4):378–387, Aug. 2010. doi: 10.1016/j.cag.2010.05.002

[69] E. E. Veas, E. Mendez, S. K. Feiner, and D. Schmalstieg. Directing attention and influencing memory with visual saliency modulation. In *Proceedings of the SIGCHI Conference on Human Factors in Comput-*

ing Systems, CHI '11, pp. 1471–1480. ACM, New York, NY, USA, 2011. doi: 10.1145/1978942.1979158

[70] I. Vollick, D. Vogel, M. Agrawala, and A. Hertzmann. Specifying label layout style by example. In *Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology*, UIST '07, pp. 221–230. ACM, New York, NY, USA, 2007. doi: 10.1145/1294211.1294252

[71] C. Weiland, A.-K. Braun, and W. Heiden. Colorimetric and photometric compensation for optical see-through displays. In C. Stephanidis, ed., *Universal Access in Human-Computer Interaction. Intelligent and Ubiquitous Interaction Environments*, pp. 603–612. Springer Berlin Heidelberg, Berlin, Heidelberg, 2009.

[72] J. M. Wolfe, K. R. Cave, and S. L. Franzel. Guided search: an alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human perception and performance*, 15(3):419, 1989.