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Augmented Reality (AR) is a new and exciting technology with wide potential implementation areas, from medical to industry. One of the fields from which AR is gaining attention is the manned security industry. Unfortunately, this is also one of the areas in which formal studies on AR is lacking. This study aims to bridge the gap in knowledge by evaluating an AR-application designed for the Microsoft HoloLens to support working security guards with navigation and a list of current tasks without negatively affecting their situation awareness.

The study is based on a pilot project in which the application was designed. Results from the pilot project suggested that participants' situation awareness was enhanced when using a round model of guidance in AR-navigation compared to when using an arrow, even though a majority of participants subjectively preferred the arrows.

In the current study, a third model of guidance was added, and potential confounding variables were controlled for. A majority of participants still preferred the arrows, however, results suggests no significant difference in participants' situation awareness between the three models of guidance. The study did not replicate results from the pilot project, this might be due to limitations pertaining to the AR-technology used in the study.

1 Introduction

Augmented Reality (AR) technology is on the upswing and is currently drawing a lot of attention from both researchers and industry (Fite-Georgel, 2011). The technology has the potential of enhancing a user's perception of the environment by projecting virtual information into the real world through computer displays and letting the user interact with it through hand gestures and voice commands (Liu & Seipel, 2018).

AR-technology is currently being explored commercially in fields such as entertainment, robotics and industry, and several AR concepts are undergoing clinical trials in the medical field (Fite-Georgel, 2011). A search for the terms "augmented reality" and "medical training" on Google Scholar yields 3250 results, and the terms "augmented reality" and "medical education" yields 5140 results on Google Scholar. One field in which AR is gaining attention from companies is the manned security industry (Peter Andreasson, personal communication, November 27, 2018). However, formal studies regarding AR in the field are still lacking. A search for the term "augmented reality" in combination with either "manned guard", "patrolling guard" or "guardian industry" yields zero results. The term "security guardian" in combination with "augmented reality" yields five results, all of which are irrelevant for the current study.

The working environment of a patrolling security guard is characterized by high risk situations, a high demand on cognitive load and difficult decisions that have to be made under time pressure. In addition, the security guard have to be vigilant about his or her surroundings at all times while carrying out the work tasks (Peter Andreasson, personal communication, November 27, 2018). Current resources used by security guards consists of handheld devices called PDAs, physical maps and radios. AR-technology has the potential to combine the functions offered by the traditional resources used by security guards in a single, head mounted device which displays useful information directly in the visual field of the user. If such an application for head mounted AR would help or simply distract working security guards is hard to say because of the lack of formal studies on the subject.

In an effort to bridge this gap in knowledge, an application for the Microsoft HoloLens was evaluated by the author. The application consists of a function for a task list as well as a navigation function through holographic 3D models displayed directly in the visual field of the user. The task list function works by image recognition. A unique image was designed and printed on a small paper that the user can hold in his or her hand, when held up in front of the Hololens, it recognizes the image and displays the current task. The navigation is made up of holographic 3D models that are placed on the floor to guide the user towards the tasks. In the pilot project, two different 3D models for guidance were designed to test participants' performance in different conditions. The application was designed in a pilot project that the author was part of (Alm, Andersson, Hellman, Josander & Månsson, 2019). The application was evaluated by its' impact on the situation awareness (SA) of the user. This was done by placing warning symbols in the environment that participants searched for while at the same time navigating and completing other tasks. Results from a user test in the pilot project suggested that using round waypoints as holographic guidance models in AR-supported navigation enhanced the SA of participants compared to using holographic arrows as guidance models. These results were interesting since a majority of participants stated that they preferred the arrows in a post-test interview. The results that the study yielded may have been caused by design flaws in the study or other confounding variables. This thesis aims to explore if results from the pilot project are replicated while controlling for confounding variables. This is done by expanding the sample, controlling for training and order effects, alternating the placement of warning symbols and by adding a third model of guidance.

2 Background and related work

I will begin by reviewing related work regarding SA and how to measure SA, visual attention and cognitive maps as well as related work in the field of AR.

Situation awareness

SA has been identified as one of the most critical factors for performance in complex tasks (McKendrick et al., 2016). A globally accepted definition of SA is still to be formulated, however, for the sake of this thesis it can be explained as a cognitive product of information-processing. SA includes the understanding of one's situation and environment as context for one's actions (Lukosch, Lukosch, Datcu & Cidota, 2015). In specific task performance, good SA is associated with goal achievement through appropriate and well timed actions in response to sensory inputs (Hendy, 1995). The mixed reality properties of AR in which a user have to immerse in the virtual components of AR and at the same time be aware of the real world creates a kind of cognitive trade-off. In this trade-off, immersion in the virtual comes at a cost of attention to the real world, possibly reducing the user's SA (Jung et al., 2018).

Endsley (1996) identifies three levels of SA; The perception of critical information, the comprehension of the meaning of critical information and the ability to project this information into the future. Complete SA thus entails more than just the perception of the environment and one's surroundings. It is also about understanding critical information in the environment and be able to understand how this information might affect one's situation as well as the future in regard to one's goals and expectations. Endsley presents a model of SA (See fig. 1). In this model, SA is one of the key factors to good decision making. In the model, working memory and attention heavily affect all levels of SA. The way attention is employed when multiple stimuli are competing for attention is essential in establishing what aspects of the situation will be processed to form the awareness of the situation. Working memory is required to integrate information with other, already known information, compare it to current goal states and project it into the future. Another important factor that comes into play in this model is long term memory in the form of mental models, mental schema, bias and heuristics. These do serve a purpose to help cognitive processes without overloading the limited capacity of working memory and attention. They can however, lead to premature conclusions when not optimal for the situation at hand. I will expand on theories of heuristics and biases in the section on interaction design. Other factors that come into play in the model are goals, expectations and automaticity, that is, how experienced the agent is with the task. However, it is important to point out that the relation between SA and performance is a probabilistic one. A person well aware of their environment and situation will not automatically perform well, but it does increase the probability of good performance (Endsley, 1996). As seen in the model (figure 1), workload is also a factor affecting SA. McKendrick et al. (2016) set up an experiment to compare navigation, SA and divided attention. Participants were using either an AR-headset or a hand-held display and were instructed to navigate around a college campus. Divided attention was assessed through an auditory n-back test and SA through questions regarding the surroundings. Pre-frontal cortex activity was measured, due to its functional relationship with working memory, using a portable version of functional near infrared spectroscopy (fNIRS). Results from the study show that the AR-headset reduced mental workload for participants while navigating compared to the hand-held device. Both groups of participants performed the task successfully, although the participants using the AR-headset showed superior working memory recall. Although hemodynamic differences were observed, no difference in performance on the SA task was observed between the groups. The authors suggests that the AR-technology still can be perfected to enhance performance on the SA tasks as well.

Measuring SA

Both direct and indirect ways of measuring SA have been proposed. McKendrick et al. (2016) used both functional neuroimaging and post-test interviews to measure workload, divided attention and SA. There are also several standardized subjective tests available, such as the Situational Awareness Rating Scale (SARS) (Endlsey, 1996).

In this study, we have chosen to use the NASA-TLX (Sharek, 2009) as a standardized test for workload along with performance measures of SA. It has been suggested that SA and workload are so closely related in their effects on task performance that they should both be measured in studies interested in either to obtain external validity (Hendy, 1995). The NASA-TLX is a multi-dimensional subjective test that gives an overall workload score (TLX-score) based on six sub-scales. The test has been widely used in numerous studies for measuring overall workload and SA, it has also been the subject of numerous evaluations regarding its reliability and sensitivity (Hart, 2006). The sub-scales included in the NASA-TLX are mental demand, physical demand, temporal demand, performance, effort and frustration. The sub-scales

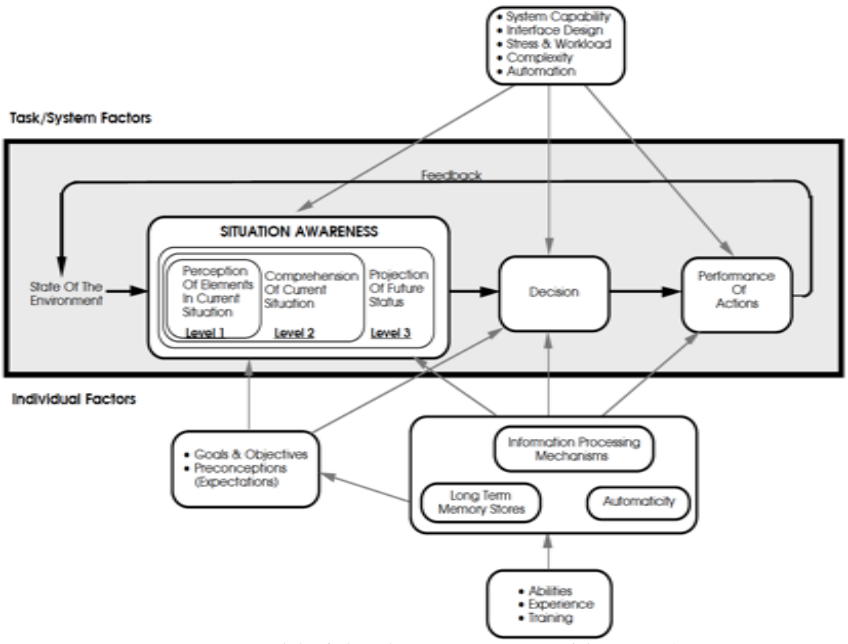

Figure 1. A model of situation awareness (Endsley, 1996).

included were selected after analysis of the factors that define the subjective experience of workload among different people performing different tasks (Hart, 2006). There is no globally accepted definition of mental workload (Qeshmy et al., 2019), the assumption, however, is that the combination of these six sub-scales gives an accurate representation of the overall workload experienced by the person taking the test. The test is taken in relation to a specific task.

A second part of the NASA-TLX is available which entails pairwise comparisons between each subscale. Eliminating this pairwise comparison, or weighting procedure have been referred to as a RAW-NASA TLX. The RAW-NASA TLX has been a popular modification of the NASA-TLX because it is simpler to apply and analyze. Results from studies that have compared the full NASA-TLX to the RAW-NASA TLX are mixed, some find the RAW-NASA TLX more sensitive, some find it less sensitive and some studies find it equally sensitive. In the words of Hart (2006, p. 906), "it seems you can take your pick". The RAW-NASA TLX will be used in this study.

Visual Attention

Attention is one of the key factors of SA (Endsley, 1996). Visual attention in particular is of great importance in the current study because the application gives no auditory or haptic feedback, the information provided by the AR-headset is purely visual.

The perceptual senses, including vision, are constantly bombarded with stimuli and we simply cannot pay attention to everything in our field of vision all the time, a selective process must be involved. Lachter, Forster & Ruthruff (2004) discusses Broadbent's original selective filter theory from 1958. The theory proposed that initial processing occurs on all stimuli to extract basic features such as color. Semantic features regarding the meaning of an object takes more capacity and is thus subject to selectivity. Only after the stimulus has been processed semantically can it be stored in long-term memory and used to form an appropriate response. This selectivity means that a lot of stimuli have to be filtered out and the process for selecting stimuli for semantic processing is both top-down guided in terms of current goals and bottom-up guided in terms of how strong the stimulus is. In short, the theory stated that people do not process unattended stimuli beyond their basic features. In the years following this original theory, it has been found that people still do identify irrelevant stimuli and the theory has been rejected (Lachter, Forster & Ruthruff, 2004).

Lachter, Forster and Ruthruff (2004) have criticized the rejections on the basis that irrelevant stimuli need not be unattended and proposed an updated version of the selective filter theory based on more recent research findings.

The underlying neuro-architectural assumptions behind Broadbent's theory seems to hold up given what we know about the visual pathways in the brain today. One example is that the visual processing system is hierarchical, meaning that simple properties are processed earlier in the visual pathways and more complex properties are processed later (Goldstein, 2011). Studies seem to also support Broadbent's notion of an "immediate" memory. In vision, this is called an iconic memory and it can hold a large amount of visual information active for a very short period of time, even if it is only displayed very briefly. The iconic memory makes it possible for someone to perceptually integrate two stimuli that are presented serially even though the presentations are extremely brief (Di Lollo, 1977).

The updated selective filter theory proposed by Lachter, Forster and Ruthruff (2004), is in essence the same as the one Broadbent proposed in 1958, except a few details. The greatest difference being that attentional shifts happen faster than proposed in the original theory. This is what led subsequent research to refute the original theory. The main claim of the updated theory is that unattended stimuli cannot be identified on the basis of semantic properties. Although some basic physical features of unattended stimuli can be processed by the iconic memory, no semantic information about them can be accessed and therefore the stimulus cannot be identified on a semantic level. The exception being if slippage of attention occurs, meaning that the observer, by mistake, directs his or her attention to a task-irrelevant stimulus for a brief period of time. A series of studies testing this updated theory supported the notion that unattended stimuli are not identified (Lachter, Forster & Ruthruff, 2004).

Studies suggest that visual attention can be divided to process and identify several stimuli, displayed on a screen, when driven by a top-down process. Whether attention is divided or not depends in large on the goals and expectations of the observer, meaning that visual attention can be deployed in either a unitary or a divided mode, switch rapidly between modes and that which mode is selected is a top-down procedure (Jefferies, Enns and Lollo, 2014). However, when visual attention is divided between different spatial locations simultaneously, feature binding errors may occur. That is, features of two simultaneously attended stimuli may be mixed together. When features of one stimulus are to be reported, these may be blended with features from the other attended stimulus. Different types of errors seems to occur based on how similar or dissimilar the attended stimuli are. One possible explanation is that the errors are driven by dynamic interactions between attended stimuli in working memory, since attention and working memory interacts with each other (Golomb, 2015).

Degradation of divided attention due to cognitive tunneling may be a risk factor in augmented reality. McKendrick et al. (2016) suggests that optimal divided attention is accomplished through rapidly shifting attention between different stimuli. Intense focus on a display when using an AR headset may instead lead to degradation of divided attention by suboptimal allocation of focused attention to different stimuli in the environment. As stated above, this is closely related to mental workload. Augmented reality can ease mental workload by displaying holograms that reduce time and distance between visual fixations, thus reducing information that needs to be held in working memory (McKendrick et al., 2016).

Where people allocate their overt attention (that is, attending by moving the eyes) can be either bottom-up driven or top-down driven. Bottom-up determinants of visual attention includes the salience of the stimulus, that is, the physical properties of the stimulus such as color, contrast and movement. Top-down determinants of visual attention includes the persons knowledge, expectations and goals and is thus dependent on the situation and the individual. Research has shown that the top-down determinants of visual attention overrides the bottom-up determinants in a task-driven situation (Goldstein, 2011).

The fact that people can direct their attention at a specific task and exclude other stimuli might be good when engaged in complex and demanding tasks. However, there is a downside to this, namely inattentional blindness. Inattentional blindness is when a person becomes blind to clearly visible stimuli in their field of vision because their attention is fixated on another stimulus or task (Goldstein, 2011). The load theory of attention states that attentional resources are finite and focusing on a certain task requires attentional resources. More demanding tasks require more attentional resources meaning that there are less resources to allocate to other stimuli. Inattentional blindness happens when there are not enough resources left to devote to other stimuli (Lee, O'Neil, & Houlihan, 2018). Just like in the model of SA proposed by Endsley (1996), inattentional blindness has to do with the limited amount of cognitive resources. When these resources are depleted, attention cannot be allocated to stimuli outside of the locus of attention and inattentional blindness happens, negatively affecting SA.

What we can conclude from the studies mentioned above, is that reduced SA, and phenomena such as inattentional blindness is affected not only by attention. Working memory, mental workload and the goals and expectations of people, among other factors, seem to interact to produce these effects. Qeshmy et al. (2019) present a framework regarding mental workload for operators in an industrialized setting and the factors that affect it. In this framework, there are five factors; thinking, deciding, counting, looking and searching. These factors affect mental workload, which in turn affect attention, attention affects performance and performance affects human errors. The idea is that automation of the five factors will reduce mental workload and thus reduce human errors.

Research findings regarding visual attention and mental workload can be used in interaction design. When using the application in the current study for example, the users will be engaged in specific tasks, meaning that top-down determinants of visual attention will likely override bottom-up determinants, unless the stimulus salience is very strong (Goldstein, 2011). Thus, if the goal of a feature in such an application is to capture the attention of the user, physical features of the stimulus has to be accentuated to increase stimulus salience.

The partial report research paradigm indicates that observers can direct their attention to the size, color or location of a cued item in a big array of items that are shown briefly. However, they are not able to direct attention to semantic properties such as the identity of a letter or even the orientation of a letter when displayed briefly (Lachter, Forster & Ruthruff, 2004). In line with the load theory of attention (Lee, O'Neil, & Houlihan, 2018), we thus proposed in the pilot project that a holographic guidance model that incorporates more semantic properties would require more attentional resources than a simpler, more ambiguous guidance model. We hypothesized that an holographic arrow, because of its directional properties, would require more semantic processing and more attentional resources than a round waypoint that has no directional properties, thus leading to reduced SA for participants using the arrows as guidance models.

Cognitive maps

To understand how best to help people in navigation, one must understand how navigation works in the human brain. One of the most prevalent theories on navigation stems from research on cognitive maps. The research domain of cognitive maps makes an effort to explain navigational behaviors on a neurological level. The term cognitive map was first used in the 1940s but was elaborated on in a book by O'Keefe and Nadel in 1978. O'Keefe and Nadel (1978) proposed two major systems that would support cognitive maps, a place system and a misplace system. The place system is a memory system that allows the organism to remember and navigate around already familiar environments. The misplace system signals changes or new elements in the environment and makes it possible to incorporate new information in existing maps or to build new maps. The authors propose a structural model of the cognitive map based on the hippocampus and place-coded neurons in the hippocampus. In studies on navigation in rodents, some navigational behaviors can not be chalked down to behavioristic associations between stimuli and rewarding responses. Some form of spatial knowledge must be involved, similar to a map. Research in the cognitive maps domain have suggested several neurobiological principles in the rodent brain. These include hippocampal neurons that fire as a function of the spatial location of the animal, neurons in several cortical and subcortical structures that fire as a function of the orientation of the head and border cells in entorhinal cortex that fire as a function of distance from navigational boundaries. These functions together are interpreted as a system for how the brain processes cognitive navigational information (Epstein, Patai, Julian & Spiers, 2017). Even though most studies on cognitive maps were first done on rodents, recent fMRI-studies using virtual navigation seem to support functional homologies to humans. Studies show that hippocampal, entorhinal cortex as well as other cortical areas are involved in storing, retrieving and using spatial information (Epstein et al., 2017). Given the importance of hippocampus in navigation and forming cognitive maps, people with impairments to the hippocampus, such as alzheimer patients, usually experience difficulties in learning new environments and navigating already familiar ones (Weisberg & Newcombe, 2016).

Studies have shown that there are individual differences in the ability to construct cognitive maps as well as differences in the strategies that people use to construct cognitive maps (Weisberg, Schinazi, Newcombe, Shipley & Epstein, 2014). Because of these individual differences, people with difficulties in navigating may be helped by having one navigational goal at a time, or by exercises that help boost working memory capacity (Weisberg & Newcombe, 2016).

In order to use these cognitive maps in a practical situation, they must be anchored to the real world in some way. This can be done in the form of landmarks in the environment. Another strategy is to start navigation at a given starting point and use self-motion cues to keep track of movement from the starting point. This strategy, known as "path integration", can be used in combination with landmarks, with the landmarks acting as recalibration points for position and heading. Other requirements for cognitive maps to be useful in real-life situations includes planning a route to a destination, calculating distance and direction. Results from fMRI-studies seem to offer neurobiological explanations for these functions as well. For example, while hippocampus seems to be of importance for retrieving path options, the pre-frontal cortex evaluates and chooses between different options (Epstein et al., 2017). AR-technology could be used to support these navigational strategies. For example, by offering landmarks in surroundings that lack other clear landmarks.

O'Regan and Noë (2001) offer a somewhat different discussion on navigation, cognition and how attention to spatial information and motor action might be closely related. Their sensorimotor contingency theory states that there is no need for an internal representation of the world in the brain. The world serves as its own representation and visual perception of it is a form of activity in which the organism has learned to master the sensorimotor contingencies that pertain to vision. Perception and spatial attention is thus a form of exploratory, visual activity and what separates visual experience from auditory experience is the structure of the rules that give rise to sensory changes produced by motor actions. Following this theory, the authors discuss spatial attention and action as controlled by the same system. One line of evidence for this is research on neglect, as neglect is an attentional deficit that stems from damage to cortical areas controlling motor activity. The sensorimotor contingency theory coincides well with notions about the world as an external memory store as discussed by Clark (2014) and the individual and the external world as one cognitive system as discussed by Hutchins (1995). These theories will be discussed in depth in the section on the importance of interaction design.

Related work in augmented reality

Xue, Sharma and Wild (2019) describe three characteristics of AR: it combines the virtual with the real world, it comprises a coordinated system with objects registered from both the virtual and the real world and interactions with objects from both worlds are possible in real time.

AR-technology has now made its way into a range of fields, including medical, robotics, military and entertainment to name a few. One of the earliest fields however, and one of the biggest steering forces in AR research is industry (Fite-Georgel, 2011). Several big companies and consulting firms have started to use AR to reduce human error and increase productivity in for example assembly lines (Qeshmy, Makdisi, da Silva & Angelis, 2019). A study investigating if AR is an appropriate tool to reduce human errors in an industrial production line found that the AR-technology is not yet mature enough to manage errors caused by humans in this setting. However, this study was conducted in a setting where the performance of workers were skill-based and there was low variance in the work carried out. The authors do not rule out that the technology can be helpful in other, more complex situations (Qeshmy et al., 2019). Other studies have shown that instructions in an assembly task in AR reduced the error rate by 82% compared to other instructional media (Tang, Owen, Biocca & Mou, 2003).

In a survey of industrial AR applications (Fite-Georgel, 2011), only two applications ever made it out of the laboratory to actually be used in the industry. Only one of these was still being used at the time of the survey. One key reason for this being that a lot of developed applications lack in end-user considerations and thus real world applicability. The author state that for augmented reality to step in to the real reality, it needs to be based on user feedback and, when possible, formal studies.

One key factor for success when it comes to the implementation of augmented reality across different domains is user satisfaction. User satisfaction can be defined as a combination of a lot of different factors, these include, but are not limited to, efficient use of time and effort, natural interactions, feelings of playfulness, immersion and engagement (Xue, Sharma & Wild, 2019). Headmounted AR-devices, such as the HoloLens, have the ability to utilize a type of noncommand user interface, where the user does not have to explicitly provide the device with commands. Instead, tasks such as providing the user with information can be accomplished by an automated process in which the device itself collects contextual information about the users' surroundings and displays useful information to the user. With this in mind, designing a good user experience for an AR-application can be different from designing for example a computer program.

Three fundamental ways in which AR-technology can help the user are by decreasing the cost of interaction to perform a task, reducing the cognitive load of the user and by combining multiple sources of information minimizing the attention switches for the user. The authors note that AR-technology does not automatically mean that users will be helped in these ways, but the success of any AR-application is dependent on a well designed user interface, for example, only showing useful information to the user at the appropriate time (Li & Fessenden, 2016).

Xue et al. (2019) investigated the user satisfaction of participants using an AR-application for the HoloLens. Results from this study shows no significant difference in satisfaction regarding the age, gender, education level, organization or roles of the participants. However, results indicate that user satisfaction is higher among participants that have better knowledge of computers and internet. There was no interaction effect between the different factors.

The aim of the current AR-application is to guide users in an indoor environment. Several propositions have been made regarding how to realize indoor navigation in AR. These include vision-based location positioning using image recognition (Kim & Jun, 2008) and indoor tracking using a 3D model of the building (Gerstweiler, 2018). For the scope of this thesis, neither of these techniques were necessary. Instead we have designed a prototype for the HoloLens in which a user can place the models of guidance in appropriate places in the environment prior to use.

The importance of interaction design

With new technology such as AR at our doorstep, we have a chance to make the right choices regarding interaction design from the start. In the following section, I will discuss theories from research regarding interaction design that inspired the project group during the development of the application.

Knowledge resides not only in the head according to Norman (1988). Knowledge can also reside in the world, in the constraints of the world or in a combination of all three. What is meant by this is that the physical world presents information and constraints regarding what actions are possible and what actions are not possible regarding certain objects and the manipulation of these.

The physical constraints of objects in combination with cultural constraints about behavior reduces the number of alternatives for any specific situation and thus reduces the amount of information required to be kept in the memory of the user. Designers frequently use this fact to organize information in the world to be available for the user when needed. This also means that memory rarely needs to be precise, memory for performing a certain task only needs to be precise enough to complete the task in collaboration with external scaffolding (Norman, 1988).

One example of this is the performance of expert bartenders. The bartenders use distinctively shaped glassware in specific arrays in order to deliver complex orders, often in a noisy environment. The distinctively shaped glasses and the order they are arranged in serve as memory cues. Without the external memory cues, the bartenders have to rely completely on their own memory system in order to successfully complete the task. In experimental settings, it has been shown that the performance of bartenders drop dramatically when only allowed to use uniform glasses (Beach, 1988, cited in Clark, 2014). One of the reasons that the shaped glasses are so helpful for the bartenders is that they offer constraints, both physical and cultural. A novice bartender would probably perform as well with the shaped glasses as with uniform glasses. The expert bartender however, has learned, through hours of practice, that certain glasses go with certain drinks for example. Some constraints may be physical, you cannot for example fit the contents of a 70 cl bottle in a 6 cl shot glass. Some constraints on the other hand, are cultural and have to be learned, for example which glasses goes with which drink. It is only when the constraints are known that they are helpful.

Constraints are not the only way that the external world can help our memory though. Sometimes the memory cues can be more explicit, such as labels and written information. The only problem with this is that it takes time and mental effort to read the information that is written. It is always better for the user when things are designed in a way so that no explicit, written information is needed. Designing with constraints is one way of putting information in the world and making interaction as easy and natural for the user as possible (Norman, 1988). Even though Norman wrote about these design principles long before modern AR-technology saw the light of day, the same principles can still be applied. The author believes that having these principles in mind, and designing AR-applications with smart constraints, memory cues and natural mappings, will ultimately lead to a more user-friendly design, whether it is regarding a tea cup or an AR-application.

The external world and the objects in it contribute not only with memory cues but they can also change the task at hand fundamentally in regards to the cognitive processes that are needed in order to finish a task. Using a pen and pencil when calculating is a simple, yet powerful example of this. Instead of having to keep an abundance of numbers in working memory, the brain can outsource parts of the task to the paper (Wallin & De Leon, 2008). In the words of Hutchins (1995), the person performing the task, the pen and the paper constitute a single cognitive system.

Now, technology has come a long way since the pen and paper, and the cognitive systems that are made up by a user and modern technology are far more complex than the pen and paper example, although the underlying principle is the same. The idea is that the brain does not function as a single, separate entity in a vacuum. Patterns of incoming sensory stimuli are associated with previously learned information and internal neural operations in an interactive relationship. We can thus transcend the limits of our own cognition by combining these internal neural operations with the external world (Clark, 2014). The cognitive processes are made easier when the props and aids of the external world are organized in a way that help reduce complex problems to ordered sets of simpler operations of the kind that the brain is more comfortable with. Executions of long, arbitrary sequences of operations are something that the brain inherently struggles with. If the technology helps or harms the situation of the user is in large part up to the designer. The potential of new technology, such as AR, is that it can help reorganize problems and present these long, arbitrary sequences of operations in ordered sets of simpler operations and let the biological brain deal with parts of the problem that it is more adapt at solving, such as the recognition of patterns (Clark, 2014). In the analogy of the expert bartender, well designed technology should provide the user with distinctively shaped glassware, ordered in helpful arrays, instead of uniform glassware that does not simplify the cognitive processes.

The importance of good design standards in technology is taken one step further by Clark (2014) in his discussion of a reciprocal evolution between technology and cognition. The reciprocal evolution is an iterative process in which a first generation of biological brains and technology influence each other to design and build the second generation and so on. As an example, the first generation of AR-technology will affect how people use the technology, and hence how and what they learn from interacting with it. This interaction will affect how the second generation of AR-technology is designed which in turn will affect the brains building the next generation and so on.

Findings from research regarding Hebbian learning as well as long term potentiation gives reason to believe that there lies some truth to the notion about a cognitive/technological evolution. Hebbian learning is a way in which the brain forms heuristics and cognitive biases. Cognitive biases can be seen on a neuronal level as the efficacy or strength of synaptic coupling between two neurons or groups of neurons, this is called connectivity bias. These connectivity biases can in turn be strengthened or weakened by Hebbian learning. Hebbian learning means that synaptic connectivity biases are strengthened by neuronal correlated activations and weakened if these activations are de-correlated. The connectivity bias is affected both by the individuals genetic makeup but also by experience and learning. Neuronal activity patterns can be seen in the human cortex even in the absence of specific tasks. The activity arising in resting state (when a person is not engaged in any intentional cognitive task) are called spontaneous fluctuations. The reason that these spontaneous fluctuations arise is unknown, although there are a few possible explanations. One explanation might be that neurons in the brain simply must stay active and emit action potentials in order to survive. Another explanation could be that the activations only appear to be spontaneous to the experimenter, but in reality they are driven by memory and motivation and are not that different from stimulus-driven activity. Regardless of the reason for these spontaneous fluctuations, it seems that they are informative about an individuals way of thinking. The theory of spontaneous trait reactivation states that the pattern of these spontaneous fluctuations offer a window into an individuals unique inner world. More specifically, a persons' connectivity bias gives the individual a unique set of personality characteristics and cognitive traits. Thus, if the patterns of spontaneous fluctuations correlate with the person's connectivity bias, then patterns of spontaneous fluctuations would be informative of that individual's personal traits (Harmelech & Malach, 2013).

Another interesting line of evidence possibly supporting the cognitive/technological evolution comes from research on long term potentiation (LTP). The theory of Hebbian learning laid the groundwork for the discovery of LTP in the 1970s, which since then has been one of the major breakthroughs in human scientific history (Patihis, 2018). In short, what LTP means is that a postsynaptic neuron undergoes long-lasting neuronal change after an excitatory signal. In an experimental setup, a presynaptic neuron is stimulated with an electrical current and the excitatory post-synaptic potential (EPSP) is measured in the postsynaptic neuron. After a period of intense stimulation, the amplitude of the EPSP is increased. This increase in synaptic effectiveness can last from a few hours to weeks or in some instances even longer (Kolb & Whishaw, 2014). Although a discussion of the results may be warranted, subsequent studies have found that LTP takes place not only after electrical stimulation but also after natural learning processes (Patihis, 2018).

So, if connectivity bias and LTP are affected by learning and experience, new technology and the use of it might affect the activity and architecture among synapses in the human brain, effectively rebuilding the synaptical structure of the brain. If true, it gives us reason the be very considerate and careful when developing new technology in order to optimize the cognitive/technological evolution.

Purpose

In this paper, I aim to investigate how to design the 3D models that are used in AR-assisted navigation to reduce exaggerated and harmful immersion in the virtual components of AR and thus enhance SA for users. Previous related work in safety-ensured immersion of AR has focused on using the capabilities of AR to prompt the user's attention towards potential risks in the surroundings. Propositions for this include designing AR to estimate vehicle trajectories through cameras and visualizing the position of the vehicle in AR, designing elaborate models that guide users to out-of-view virtual objects and displaying driving information in AR directly on a vehicles windscreen (Jung et al. 2018; Bork et al. 2018; Lin, Lin, Dow & Wong, 2011). One potential problem with all of these propositions is that the models that are meant to alert users to potential risks must be displayed in the AR field of view, occluding parts of the user's view of the real world.

The extremely popular mobile game Pokémon GO that was launched in 2016 was one of the mainstream breakthroughs of AR-technology. Ayers et al. (2016) estimated over 100 000 incidences related to Pokémon GO reported on Twitter in just 10 days in 2016. These "tweets" regarded pedestrians that were almost involved in accidents while playing the popular AR game, and car drivers or passengers in cars that were playing while the car was driving. Examples of tweets include "omg I'm catching Pokémon and driving", "almost got hit by a car playing Pokémon GO" and "my mom is driving me around to help me find Pokémon lmao".
The cognitive trade-off between virtual immersion and SA (Jung et al., 2018) could be one of the reasons for the Pokémon GO-related incidents.

To test for SA while following different 3D models of guidance in AR, three 3D models were designed (see figure 2). The arrow and the waypoint were used in the pilot project to test for differences between a model with direction (arrows) and one without direction but with a slight vertical extension (waypoints). A third model with neither direction nor vertical extension (the puck) was added to the current study to control for the difference in vertical extension in the two other models.

In line with results from the study in the pilot project, I expect that participants will exhibit enhanced SA in terms of noting more warning symbols while using the waypoints as guidance models than when using either the arrows or the pucks. I also expect that a majority of participants will subjectively prefer the arrows as guidance models when asked in the post-test interviews.
I expect to see no significant differences between models of guidance in the RAW NASA-TLX scores.

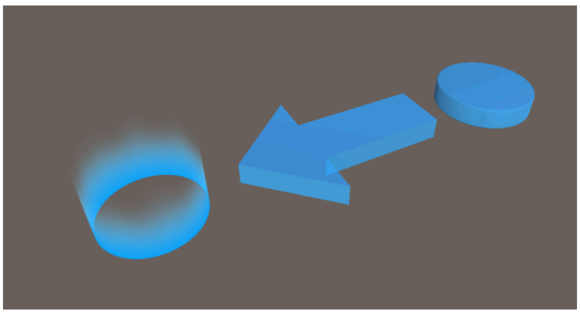

Figure 2. Three different models of guidance. From left to right: a waypoint, an arrow and a puck.

3 Method

Participants

30 participants volunteered for the study, 16 male and 14 female, aged between 20 - 40 (M = 25.3, SD = 3.88). The sample was selected through convenience sampling. 26 of the participants had never tried head mounted AR before, 4 participants stated that they had tried it before, but not in a guiding scenario. 26 participants were students, the other 4 participants were working full-time. Use of corrective glasses was controlled for, two participants who usually wear corrective glasses did not use them during the test, however, both stated that this should probably not affect their performance since their vision impairments were mild.

Material

The main hardware used in this study was the Microsoft HoloLens (See fig. 3). The Microsoft HoloLens is a head mounted AR device. The HoloLens is completely self-contained, meaning that there are no external parts, wires or need for a connection to an external PC (Microsoft, 2016). This mobile device suits the needs of the study. Three A4 papers with printed pictures of a red warning triangle symbol were used for participants to locate during the test, and a small paper was provided with a logo that displayed a hologram with the current task when viewed in AR (See fig. 4).

An electric fan and a small, red, LED-light was used as objectives in the tasks during the test. Participants signed an informed consent form on a paper and wrote down their participant ID, demographics and the amount of warning symbols

Figure 3. The Microsoft HoloLens (https://images.app.goo.gl/oYzfPpasaZuCH8vQ9).

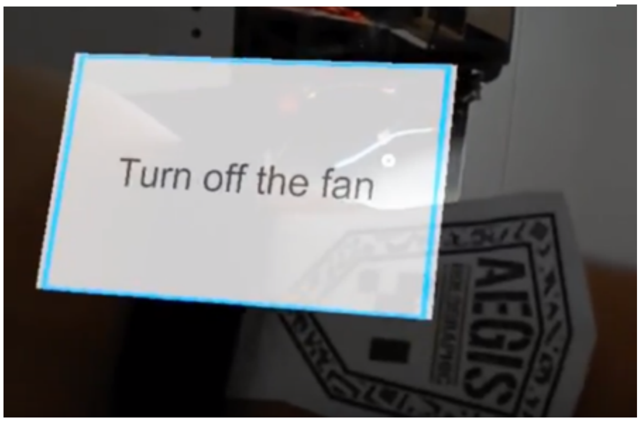

Figure 4. The current task being displayed in AR.

they saw on another paper. A laptop was used for the participants to take the RAW-NASA TLX test. All trials and post-test interviews were video recorded using a standard digital camera.

Procedure

The user tests took place in the humanities laboratory at Lund University. When arriving, participant signed an informed consent form and a pre-test form for demographics, use of corrective glasses, profession and experience with head mounted AR. After filling in the form, participants read instructions for the test and got to try the HoloLens to familiarize themselves with the hardware. A within subjects design was used, in which each participant did three trials each, one with each guidance model. Each trial started with the participant standing at the start of a corridor in the humanities laboratory. They were given a small, hand-held paper displaying their current task (see figure 4) and a HoloLens and all further instructions were given by the HoloLens. The test consisted of following a guided route through a corridor and into a second room in the humanities lab. There were several doors in the corridor which meant that participants had to follow the guidance symbols to find the right room in which the final task was located (see figure 5).

During the trial, participants had two simple tasks to complete, turning off a fan in the corridor and turning off a light in the second room. The small, hand-held paper (see figure 4) displayed their current task and by saying the voice command "next" the next task was displayed. When completing the last task and saying the voice command "next", "all tasks completed" was displayed, meaning that the trial was finished. During each trial, three warning symbols printed on A4 papers were placed in the surroundings and participants were instructed to take note of how many warning symbols they saw during the trial. The guidance models and placement of warning symbols were switched between trials so that each participant did one trial each with all three guidance models. Three different models of guidance and three sets of warning symbol placements created 18 unique combinations of trials that were alternated between participants to control for training and order effects. Between each trial, participants did the RAW-NASA TLX and filled out how many warning symbols they saw during the trial. The test leader timed each trial and each trial was video

Figure 5. The corridor in which the trials took place, seen from the starting point with holographic arrows as guidance models.

recorded by a stationary camera in the corridor. After completing the third trial, participants were asked semi structured interview questions about their subjective experience of the AR-application and what guidance models they preferred. The whole user test took 30 minutes per participant to complete. Although each trial was timed, participants were not instructed to complete the trial as fast as possible but only to complete the tasks and be vigilant about warning symbols in their surroundings.

4 Results

Contradictory to the first hypothesis, a one-way repeated measures ANOVA showed no significant difference in how many warning symbols participant found between the waypoints models (M=2.33, SD=1.06), the arrows models (M=2.3, SD=0.92) and the pucks models (M=2.53, SD=0.68), $F(1.85,53.67)=0.565$, $p=0.559$ (see fig. 6).

To control for training effects, a one-way between subjects ANOVA was conducted using only the first trials of each participant, resulting in 10 trials for each participant. The ANOVA showed no significant difference in how many warning symbols participant found between the waypoints models (M=2, SD=1.41), the arrows models (M=2.1, SD=0.99) and the pucks models (M=2.4, SD=0.7), $F(2,27)=10.83$, $p=0.692$.

To control for novelty effects, a one-way between subjects ANOVA was conducted using only the last trial for each participant, resulting in 10 trials for each participant. The ANOVA showed no significant difference in how many warning symbols participant found between the waypoints models (M=2.7, SD=0.48), the arrows models (M=2.4, SD=0.7) and the pucks models (M=2.8, SD=0.63), $F(2,27)=1.16$, $p=0.329$. Figure 6 displays how many warning symbols participants found in each condition.

In line with the third hypothesis, a one-way repeated measures ANOVA showed no significant difference in RAW-NASA TLX-scores between the waypoints model (M=19.89, SD=14.54), the arrows models (M=18.75, SD=12.12) and the pucks models (M=19.40, SD=15.99), $F(1.97,57.08)=0.089$, $p=0.912$ (see fig. 7).

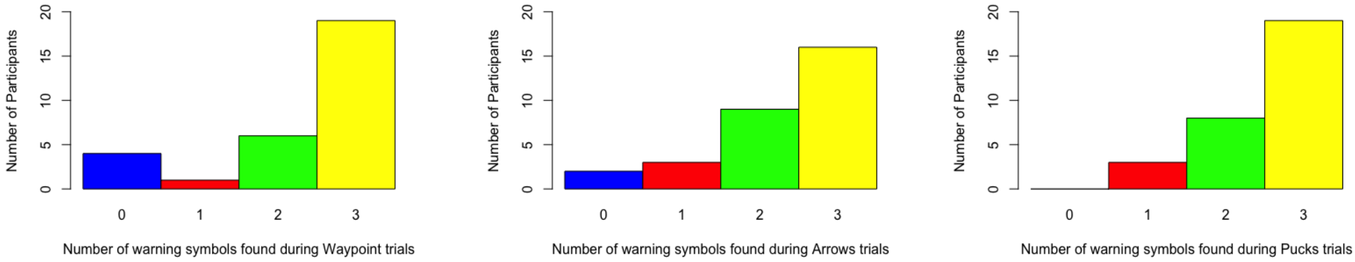

Figure 6. Number of warning symbols found per condition.

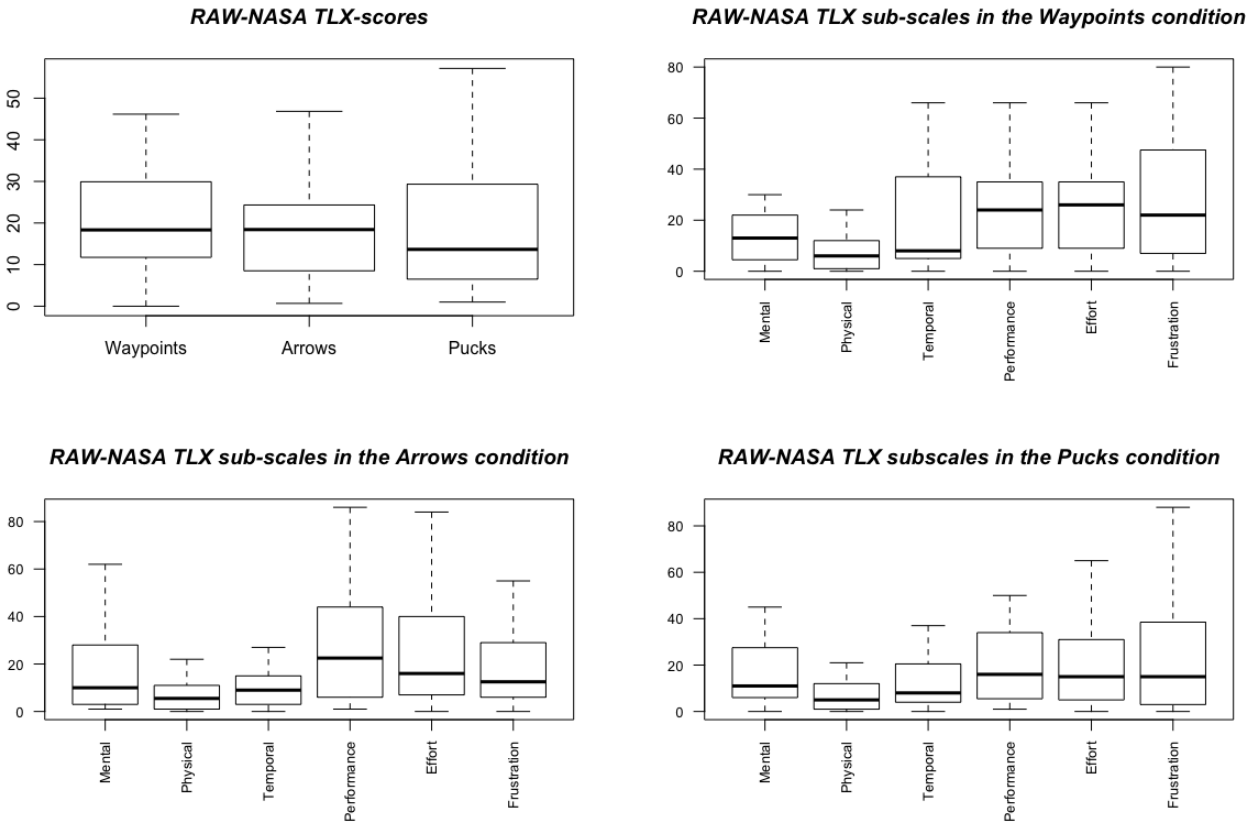

Figure 7. Upper left: TLX-scores from all three conditions. Upper right: Sub-scales in the waypoints condition. Lower left: Sub-scales in the arrows condition. Lower Right: Sub-scales in the pucks condition.

Figure 7 displays RAW-NASA TLX-scores for all three conditions as well as scores for all sub-scales per condition.

Results from the post-test interviews are displayed in the pie-charts (See fig. 8). Out of 30 participants, 22 preferred the arrows as guidance models, 6 participants preferred the waypoints, 1 participant preferred the pucks and 1 participant had no preferrence. This supports the second hypothesis that a majority of the participants would prefer the arrows as guidance models.

In the post-test interviews, participants were also asked if they understood the instructions that they read prior to beginning the first trial and if they undertood the tasks given by the Hololens. All participants stated that they understood the instructions and the tasks.

At the end of the post-test interviews, participants were asked if they had any other comments. Out of 30 participants, 17 had no other comments, 5 participants stated that they thought that the waypoints looked "best" or "coolest" and 8 participants stated that they were very focused on the direction that the arrows were pointing in to the extent that they were distracted from searching for the warning symbols.

5 Discussion

The aim of the study was to see if results from the pilot project were replicated. Results from the pilot project indicated that participant's SA was significantly improved, in terms of noting more warning symbols in their surroundings, by using waypoints as guidance models in AR compared to using arrows as guidance models. These results were not replicated in the current study. It was hypothesized that participants would perform better in the waypoints condition than in either the arrows or the pucks condition. In the pilot project, only the waypoints and the arrows were tested. The pucks were added in the current study to control for the difference in vertical extension between the waypoints and the arrows. If the results

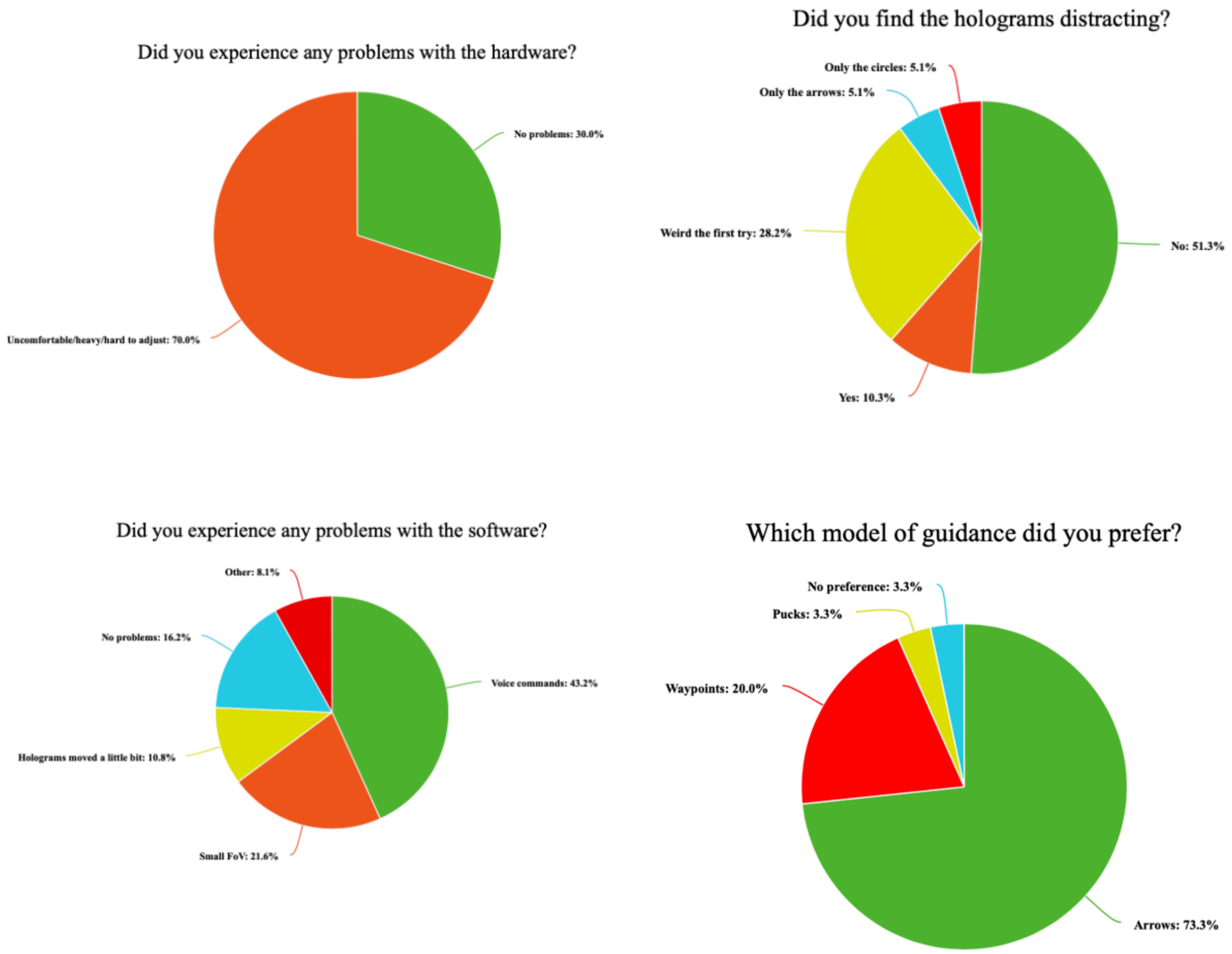

Figure 8. Pie-charts displaying results of the post-test inter-views, shown in percentages.

obtained in the pilot project were due to the difference in vertical extension between the two models, adding a third model with neither direction nor vertical extension (the pucks) should have controlled for this. It was hypothesized that participants would perform better in the waypoints condition than in the pucks condition because the lack of vertical extension in the pucks model would force participants to tilt their head down to see the guidance models at the cost of SA.

Results from the current study showed no significant difference between any of the three models, even after controlling for training and novelty effects by removing the last two and the first two trials. The negative effects of a guidance model with direction on SA need not be completely refuted on the basis of these results. Out of 30 participants, 8 participants stated in the post-test interviews that they were very focused on the direction of the arrows to the extent that the were distracted from searching for warning symbols at the same time. Reasons that the results do not reflect this might be because of technological or methodological limitations. These will be discussed in depth in the following sections.

The second hypothesis was that a majority of participants would prefer the arrows as guidance models compared to either the waypoints or pucks. This hypothesis was based on results from the post-test interviews in the pilot project. Out of 30 participants, 22 preferred the arrows as guidance models, confirming the second hypothesis. All participants who preferred the arrows stated that they did so because the directional properties of the arrows made it easy to understand in which direction they could find the tasks that they were meant to complete in the test. This could implicate that a guidance model with directional properties is to be preferred when the goal of the model is to simply guide a user towards a goal. However, in a situation where SA is a factor, such as in the case of a working security guard, the hypothesis was that the directional properties of the arrow might create a kind of cognitive tunnel vision, impairing the SA of the user. Further studies are required to draw any conclusions on this theory.

The third hypothesis was that there would be no significant differences between models of guidance in the RAW-NASA TLX-scores. The RAW-NASA TLX is a subjective test of mental workload and the TLX-scores gives an overall score for workload over six subscales. The route, tasks and instructions remained the same between trials, the only variables that differed for the participants between trials were the models of guidance and the placement of warning symbols. It was believed that this change would not be enough for participants to subjectively rate the trials differently regarding any of the six subscales in mental workload. A one-way repeated measures ANOVA showed no significant difference between models of guidance in the the RAW-NASA TLX-scores, confirming the third hypothesis.

Technological limitations

Possible limitations with the current study include technological limitations regarding the Microsoft HoloLens. One of the most obvious technological limitations is the field of view (FoV) of the HoloLens. The FoV was mentioned by 7 participants out of 30 in the post-test interviews as a limitation that might have affected performance. The FoV in the HoloLens is estimated to be about 30°×17.5° per eye, compared to the human visual field of about 200°×130° (Kreylos, 2015). This means that the area in which a user can see holograms does not cover the full FoV of the natural human eye. Instead, holograms only appear in a small square in the center of the visual field, meaning that the user has to turn his or her head in order to see the holograms. When the holograms are displaced in the perifephery of the visual field of the user, they simply vanish. This might interfere with the user's sense of object permanence, and thus affect the performance of the user.

Another possible limitation with the HoleLens was the voice commands. 13 participants stated that the had problems with the voice commands atleast once during the trials. This usually was resolved by saying the voice command again until the command was registrered. However, having to paus in the middle of a trial might cause disruption, affecting the performance of the participants.

Other limitations regarding the software include 3 participants that stated that the holograms moved a little bit. Not enough to throw them off course but swayed a bit in place, confusing the participants. One participant had problems with the image recognition during the last trial and one participant had the menu pop up in the HoloLens when starting one of the trials.

Other limitations regarding the HoloLens pertain to the hardware. In the post-test interviews, 20 participants stated that they experienced that the HoloLens was uncomfortable, a bit heavy on the head or hard to adjust.

In summation, every participant experienced problems with either the hardware or the software during the test. When the technology does not work as intended, limitations such as heavy and uncomfortable hardware might steal focus from the task at hand. As discussed by Hendy (1995), SA is associated with goal achievement through appropriate and well timed actions in response to sensory inputs. If too much of the sensory inputs are task-irrelevant, such as faulty technology, it might lead to reduced SA. As the study was aimed at investigating participants' performance in relation to SA, these limitations taken together might have affected the outcome of the study.

Methodological considerations and future research

The lack of significant results in the analysis warrants a discussion on the methodological choices of the study. The study aimed to partially replicate the user tests from the pilot project. This fact, along with technological limitations, lead to methodological choices when designing the study.

The state of contemporary AR-technology, the HoloLens and the scope of this study lead to a relatively short route for participants to navigate during the trials. The total route was approximately 20 meters. Because of the mobile nature of the study, the HoloLens required a specific environment. Too many people, noise, ambiguous colours on the walls and floors or other disturbing elements would cause the HoloLens to lose tracking of the environment and it would not have been possible to carry out the study. Other locations were tested before deciding on the humanities laboratory, however, the laboratory was the best suited location for the study. Furthermore, the route stayed the same between trials in the current study. The navigation in the application functioned by the experiment leader placing the models of guidance on the appropriate spots before the trial. Given the time it took to place models of guidance, and the relatively unstable nature of the technology, it would not have been reasonable to change the route by changing the placement of models of guidance between each trial. In future studies, if the technology is improved and allows for it, a longer route, and alternating between different routes to control for training effects should be used to increase external validity.

Three warning symbols were placed in each trial for the participants to find. The reasons for not placing more warning symbols in the environment were partly because of the short route that participants navigated, and partly because the pilot project, which yielded significant results, used three warning symbols. A longer route, if possible, would have allowed placing more warning symbols which might have allowed for a bigger difference in SA to be detected between conditions. The number of warning symbols detected was the dependent variable in the current study and the low number of warnings symbols might have affected the power of the study. In future studies, it is suggested that more warning symbols are used if possible in order to increase the power of the study.

Another possible explanation that the pilot project yielded significant results that the current study did not replicate is the fact that the placement of warning symbols were not alternated in the pilot project. The placement of warning symbols in the pilot project were static and unique for the waypoints and arrows trials. Great care was taken in order to place the warning symbols in places equally hard to find between conditions, however, the results yielded in the pilot project might simply have been because participants found the warning symbols in the waypoints condition easier to find. In the current study, the placement of warning symbols were alternated between trials and conditions in order to control for this possibility.

In order to have the possibility to collect qualitative data from participants regarding subjective opinions on the different models, a within subjects design was used in both the pilot project and the current study. In future studies, a between subject design might be employed in order to eliminate training and order effects.

Conclusion

In a contemporary study by Qeshmy et al. (2019), it was concluded that AR-technology is not yet mature enough to manage human errors in an industrial production line. The current study verifies this conclusion. The author would not yet refute the negative effects of models of guidance with directional properties on SA, however, the current study did not find any evidence supporting this theory, possibly because of technological limitations.

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