Introducing hybrid foraging search as a potential bedside tool for assessment of visual attentional disorders

Lærke Fahl

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Vejleder: Thomas Alrik Sørensen

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Abstract

This study proposed an alternative way of assessing visuospatial neglect by using a hybrid foraging task. The hybrid foraging task used in this study has previously been used in laboratory settings as a measure of visual attention. This study aimed to determine if the hybrid foraging task can be performed on a tablet with a touchscreen, thereby enabling bedside assessment. Furthermore, this study also aimed to explore the performance on the task on a sample of neurologically healthy older adults in Denmark. Specifically, a measure of the spatial placement of each clicked object was added and used to determine if there were any differences in performance on the hybrid foraging task when collecting targets in different areas of the screen. The hybrid foraging behavior found in this study was expected to correspond to data previously collected on a similar age group in America using the same task.

All participants included in this study were 65 years or older and reported having no neurological disorders. This study included three experiments. The first experiment was aimed at assessing the testing procedure and the initial feedback of the hybrid foraging task from participants (n = 2). In this experiment, a difference was found between the foraging behavior in the first and second block of the hybrid foraging task, with both participants foraging more optimally in the second block. The second experiment was aimed at examining the difference in foraging behavior in the two blocks. The participants in the second experiment were the same as in the first experiment. The results of the second experiment indicated that performance on the hybrid foraging did not appear to keep changing after the second block, however the pattern was still somewhat unclear, and therefore this was investigated further in the third experiment. The aim of the third experiment was to collect data on the hybrid foraging task performed on a tablet by a larger group of Danish older adults (n = 40). After completing the hybrid foraging task, the participants were asked to answer a questionnaire regarding their experience of the

task and demographic information about themselves. Their performance on the hybrid foraging task was analyzed and compared to the two previous experiments as well as prior research.

The performance on the hybrid foraging task, as well as the responses on the questionnaire, indicated that the hybrid foraging task can be made available for bedside assessment by being performed on a tablet. Furthermore, the results indicated that the task demands and the administration on a tablet was appropriate for this sample of older Danish adults. By assessing the results of the spatial measure, several patterns were found in the participants' performance on the task. Most notably, a naturally occurring pattern of object collection was found, with participants tending to collect most objects near the center of the screen and collect few objects in the corners of the screen. The general pattern of foraging behavior found in previous research using the hybrid foraging task was found to be replicated in a sample of older adults in Denmark. Furthermore, the age-related decline in optimality of foraging behavior, that has previously been found, was replicated within the sample of older Danish adults in this study. While this study can be seen as the foundation, further research is needed to investigate the hybrid foraging task's ability to detect visuospatial neglect in patients.

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Introduction

In our daily lives, attention plays a vital, but often unnoticed, role in managing the large amounts of sensory information we are presented with at all times. Attention enables us to selectively focus on and process the relevant stimuli, while leaving the irrelevant stimuli unattended. While attention can be devoted to all sensory modalities, this study will focus mainly on visual attention.

An example of visual attention could be searching for a friend at a busy train station. You know that the friend you are searching for has distinctive blond hair. Instead of examining every person at the train station, you can purposefully focus your visual attention on individuals with blond hair. By doing this, you are able to find your friend more effectively in the crowd. Another example of deploying visual attention could be reading this text, or noticing when someone enters the room. As illustrated by the diversity in these examples, visual attention is an integral part of our everyday lives. However, deficits in visual attention can occur following a stroke. In Denmark, approximately 1 out of 7 individuals will experience a stroke at some point in their lives (Sundhedsstyrelsen & Dansk Råd for Genoplivning, 2020). A commonly observed deficit in visual attention after stroke is visuospatial neglect, where people fail to attend to stimuli in a specific part of their visual field. This condition is associated with a higher risk of accidents (Tromp et al., 1995). For this reason, it is crucial to have effective testing methods for visuospatial neglect that do not allow people to compensate during assessments.

The current study proposes an alternative approach to testing for visuospatial neglect, aiming to develop a tool for assessment that measures a broad range of parameters, allows for bedside testing, and prevents compensatory behaviors. By developing better testing methods, we can enhance our understanding of visual attention deficits, with the ultimate goal of improving patient outcomes.

Before the proposed assessment tool can potentially be used to test for visuospatial neglect, it is first necessary to evaluate if the method is appropriate for use as a bedside test. This paper will begin by exploring the history and current research on attention, including research on visual attention. The assessment of visual attention through different types of visual search tasks will also be reviewed. Next, this paper will investigate what happens when there are deficits in visual attention. Specifically, visuospatial neglect will be defined, and the available assessment methods for this visual attentional disorder will be explored. This will lead to a presentation of the hybrid foraging search task as a proposed tool for bedside assessment of visuospatial neglect. This paper will assess the use of the hybrid foraging task on a sample of older Danish adults, with the aim of evaluating if the task can be used as a bedside tool and exploring how a group of neurologically healthy older adults perform on the task.

Attention

First, the concept of attention will be explored. While attention can be devoted to all sensory modalities, the focus in this project will be on attending to visual stimuli. However, many of the things learned about attention from studying other modalities, such as hearing, are relevant to mention as these can also be applied to visual attention.

History of attention

Before attention was studied in the field of psychology, it was originally studied by philosophers. Juan Luis Vives, who lived in the 16th century, was a philosopher who is now mostly known for his work on memory, where he believed that attention was an important factor. Vives concluded that the more carefully one attends to stimuli, the better the memory of the stimuli will be (Watson, 1915). Centuries later, the subject of attention was taken up again by the early psychologists. One of these early psychologists was William James, who, with his book “Principles of Psychology”, is considered one of the large influences on early cognitive psychology (Matlin, 2009). In 1890, James defined attention as “the taking possession by the mind in vivid form, of one out of what seem several simultaneously possible objects or trains of thought" (James, 1890/1950). James believed that paying attention to one thing consequently meant that other things would remain unattended. Furthermore, he proposed that there are two domains in which attention can be allocated: the sensory domain and the intellectual domain. In the sensory domain, attention could be allocated by attending to external stimuli that can be perceived, while attention could be allocated to thoughts, memories, or other internal processes in the intellectual domain (James, 1890/1950).

Since then, many have attempted to produce an encompassing definition of attention, yet there is no uniformly accepted definition of attention (Fernandez-Duque & Johnson, 2002; Pashler, 1998). Neisser (1976) defined attention simply as the allocation of resources and processing to a region, object, or dimension. Others have prioritized James' distinction between the types of attention given to internal processes and the types of attention that can be paid to the outside world, as an important feature of attention (Friedenberg, 2013).

Although James' definition of attention was formulated 133 years ago, the main ideas are still seen in the definitions used today. The American Psychological Association's (2023) definition of attention is rooted in the idea that the allocation of attention toward one item is done at the expense of not focusing on other items. Here, attention is defined as "a state in which cognitive resources are focused on certain aspects of the environment rather than on others…" (American Psychological Association, n.d). This is in line with other mainstream literature on attention, where the consensus is that our attentional resources are finite, and an integral part of attention is therefore choosing what should be attended to and what we can forgo (Matlin, 2009).

Theories of information processing

This idea that only a limited amount of information can be processed, and that the information from the external environment must therefore go through some kind of filter, is one that was originally proposed by Broadbent (1958). According to Broadbent's filter model of attention, we first process all stimuli from the external environment at a very basic level. At this level only the basic physical properties are processed, and this information is then held in a preattentive buffer. Only after specific stimuli have been selected for attentional processing will the semantic features of the stimuli be processed. The information that is held in the preattentive buffer, but not attended to, will not be processed and the unattended information will be lost (Broadbent, 1958). Broadbent's theory has since been categorized as an early selection theory of attentional processing (Matlin, 2009). However, the filter model of attention has been criticized for being an all-or-nothing theory that does not allow for flexibility in the allocation of attention (Schneider & Shiffrin, 1977).

Others have also theorized where in the process stimuli is selected for attentional processing. One such theory was proposed by Deutsch and Deutsch (1963), who believed that the selection of what stimuli will be attended to happens very late in the processing. According to this late selection theory, all stimuli from the environment are semantically analyzed before attention is allocated to the most relevant stimuli (Deutsch & Deutsch, 1963). Often the late selection model of attention is seen as unlikely, since it seems wasteful that the human mind should fully semantically process so many stimuli, while only attending to a small part of it (Nordfang & Nørby, 2017). However, unlike Broadbent's filter model of attention, the late selection model of attention can be applied to explain the cocktail party effect, first described by Cherry (1953). This effect investigates how people are able to selectively listen to only one conversation while ignoring other conversations happening around them, yet if the person's name is mentioned in one of these other conversations, often they will still pick up on this (Cherry, 1953; Moray, 1959).

The cocktail party effect can also be explained by Treisman's (1964) attenuation theory of selective attention. While this theory of attention still proposes that selection happens very early in the processing of information, here the selection process is much more flexible. Instead of a filter, Treisman (1964) proposes that all information from the environment goes through an attenuator that weakens information that is not attended to, but it does not eliminate this information completely. This allows us to semantically process attended information, as well as some unattended information, although to a lesser degree. If the semantic processing of the unattended stimuli seems important enough, such as hearing our own name, our attention can then be switched to focus on this information instead.

Distinctions in attention

The above-mentioned discussion about when stimuli is attended to is only one of many in the research field of attention. Many of these discussions center around different aspects of attention, such as the concept of sustained attention as well as the distinctions between bottom-up and top-down attention, between overt and covert attention and between focused attention and divided attention. These distinctions will be expanded upon in the following sections.

Bottom-up and top-down attention.

Attention can be allocated to a stimulus either automatically or by choice. Bottom-up attention is an automatic process, where attention is allocated to some stimulus in the environment, based on factors such as brightness and physical salience. This type of attentional deployment begins at the basic levels of object recognition and then works its way up to the higher cognitive levels (Melloni et al., 2011). Because the bottom-up process of attention allocation is automatic, it is characterized by being quick and outside of the person's voluntary control (Nordfang & Nørby, 2017). Top-down attention, on the other hand, is an active and voluntary allocation of our attention. Here we use expectations and prior knowledge to guide our attention toward a particular stimulus. By using our cognitive strategies in this way, attentional control begins at the higher cognitive levels and works its way down to the bottom levels (Connor et al., 2004).

Overt and covert attention.

Another distinction in attention types can be found between overt and covert attention. Overt attention is often defined by our eye movements and entails paying attention to what we can be seen looking at (Friedenberg, 2013). In contrast, covert attention is attention without eye movements or other forms of physical orienting towards the attended stimuli (Posner, 1980). Like other types of attention, both overt and covert attention can be allocated either automatically by bottom-up processes or voluntarily by top-down processes (Carrasco & McElree, 2001).

Posner (1980) used a cueing paradigm to demonstrate how the allocation of covert attention to a location, prior to showing the stimulus, reduces the reaction time of overt attention when the stimulus is shown. In this paradigm, participants were asked to fixate on a point in the middle of the screen, and a cue would be presented on either the right or left side of the screen. After a short interval, the target stimulus was then shown on either the same side of the screen as the cue or on the opposite side of the screen. If the target was shown on the same side as the cue, the participant could covertly attend to that side before the target presentation, which shortened the reaction time (Posner, 1980). This indicates that covert attention can be used prior to directing overt attention to a target in order to speed up reaction times.

Focused attention and divided attention.

Yet another distinction between the types of attention can be found between focused attention and divided attention. In general, focused or selective attention requires people to focus on only one thing, while divided attention requires focusing on several stimuli at the same time (Matlin, 2009).

Using focused attention entails selecting some area or stimuli to focus on, and thus not selecting other stimuli, as previously described in James' definition of attention. Focused attention can be demonstrated by the cocktail party phenomenon, where people are able to focus their attention on only one conversation in a room full of other conversations (Cherry, 1953). There are two especially influential metaphors of focused visual attention. The first of these is the spotlight metaphor. Through this metaphor, visual attention cannot be allocated to our whole environment but is instead focused with a beam that may vary in size. All stimuli within the spotlight are believed to be clear, while stimuli left outside the spotlight are blurry and unclear (Posner et al., 1980). The other metaphor used is the one comparing visual attention to a zoom lens. The comparison to a zoom lens is chosen because this allows the size of the attentional field to both increase and decrease in size. Like with a zoom lens, the smaller the attentional area is, the more focused it will be, whereas the details in larger attentional areas are a little more blurry (Eriksen & St. James, 1986).

The other type of attention is divided attention, which is seen when a person attempts to focus their attention on several different things or areas at the same time. Oftentimes, divided attention performance is not very good, especially for challenging tasks, but performance can be improved with practice (Hyman et al., 2010; Wikman et al., 1998).

Sustained attention.

When we focus on something for an extended period of time, we are employing what is known as sustained attention (Esterman & Rothlein, 2019). Sustained attention is sometimes also known as vigilance or concentration (Filley, 2002). The ability to focus our selective attention for a duration of time is vital for our everyday lives, in tasks such as reading a book or driving a car.

Sustained attention is often assessed using tasks, where the participant is required to concentrate on the task over a prolonged period of time and is asked to respond to specific types of stimuli only and ignore all other stimuli (Staub et al., 2014). It has been shown that older adults, defined as people over 70 years, begin to experience a decline in sustained attention performance. This can be seen as a general slowing of reaction time, when older adults are shown a stimulus and need to decide if they should react or ignore the stimulus (Filley & Cullum, 1994). Furthermore, it has been found that when increasing the difficulty of a sustained attention task, older adults are likely to focus on accuracy of responses at the expense of reaction time (Thomson & Hasher, 2017). This is in line with the results from a study of over 10.000 participants, which found that the strategy used on a sustained attention task changes with age. Specifically, participants became more conservative with age, meaning that they again have a tendency to sacrifice reaction time speed and instead focus on accuracy of response, when compared to younger adults (Fortenbaugh et al., 2015). So, although older adults retain their ability to employ their sustained attention to a task, a gradual age-related slowing of reaction time is seen.

Neuroanatomy of attention

Attention is a complex phenomenon that is integral to our experience of the world and consequently involves much of our brain. Two major neural networks have been suggested to mediate our attention (Corbetta & Shulman, 2002). The first of these is the dorsal frontoparietal attention network. In general, the dorsal frontoparietal network of attention is believed to be the basis of voluntary control and orienting of attention (Corbetta & Shulman, 2002). This network is bilaterally organized and consists of areas in the dorsal frontal cortex, such as the frontal eye field and the supplementary eye field, and areas in the dorsal parietal cortex, such as the medial intraparietal sulcus and superior parietal lobule (Szczepanski et al., 2013).

The other major attentional network is the ventral frontoparietal attention network. This network is concerned with the bottom-up reorienting of attention on the basis of the environment. Whereas the previously mentioned dorsal network appears to be bilaterally organized, this ventral network seems to be lateralized to the right hemisphere (Corbetta & Shulman, 2002). The ventral frontoparietal network consists mainly of the ventral frontal cortex and the temporoparietal junction (Corbetta & Shulman, 2011).

It is thought that these two attention networks always work in collaboration to control attentional processes, and that neither network can do this by itself (Vossel et al., 2014).

Visual search

People often combine several of the aforementioned types of attention to complete tasks in their everyday life. For example, when searching for a friend at the train station or finding Waldo in a children's book, this necessitates using several types of attention, including focused attention, top-down attention and the ability to sustain attention in order to complete the task. The ability to conduct a visual search of a scene is relevant to understand, because it is something that people do every day, often without noticing that they're doing it. In some instances, it can even be lifesaving, such as when radiologists look for abnormalities in scans or when airport security searches people's luggage for dangerous items (Wolfe et al., 2005). For these reasons, tasks like finding Waldo, and other tasks where the participant is asked to search visually, are often used to investigate visual attention (Davis & Palmer, 2004).

Mechanism of visual search

In a classical visual search task, the participant is looking for a single instance of a specific target object among the distractor objects (Wiegand & Wolfe, 2020). When assessing visual search, a distinction is made between two different mechanisms of search, based on whether the search is serial or parallel. The basic assumption is that only one stimulus can be attended at a time in serial search, while multiple stimuli can be attended at the same time in parallel search (Egeth, 1966). Parallel search can be used when searching for individual features in our visual field and is therefore also known as feature search. In search tasks requiring feature search, the target objects are often described as "popping out" from the distractor objects (Wolfe, 1992). An example of feature search could be searching for a red letter T among blue T's. In such a task, it is easy to imagine that the red T would "pop out" on the page because of the color difference. Here, the search for the target object can be led by the bottom-up automatic orienting of attention previously described (Melloni et al., 2012).

Serial search is more complicated and requires integrating or combining several features to detect the presence of a target. This is also called conjunction search. An example of conjunction search could be asking a participant to find the red T among blue T's and red X's or asking a participant to find Waldo on a crowded page. This type of search task takes significantly longer than feature search and requires focused top-down attention to be directed to each object in order to determine if it has the correct conjunction of features (Treisman & Gelade, 1980).

Feature Integration Theory

Based on the research on feature search and conjunction search, Treisman and Gelade (1980) proposed the Feature Integration theory. According to this theory, the visual field is processed in two stages. First all features in our visual field are preattentively registered. This is simple and effortless and is done automatically and in parallel. In the second stage, focused attention is used to combine the individual features in order to identify the object (Treisman & Gelade, 1980). This theory has become an important framework for understanding visual attention and the following research on the topic (Matlin, 2009).

Guided Search Theory

Feature integration theory was criticized by Wolfe and colleagues (Wolfe et al., 1989). They highlighted that the Feature Integration theory did not give the preattentive processing stage any influence on the subsequent serial processes used to identify the conjunction of features and noted the intuitiveness of a connection between the two processes. In response, they present the Guided Search theory. According to this theory, the spotlight of focused attention is guided by the initial parallel processing of individual features. The parallel feature search and the serial conjunction search is here not seen as distinct processes, but interconnected, because the feature processing guides the later conjunction search (Wolfe et al., 1989).

The Guided Search theory has since been revised several times and is now in its sixth iteration. In the newest iteration, attention is thought to be guided by five different kinds of preattentive processing: top-down feature guidance, bottom-up feature guidance, prior history, reward, and scene guidance. Information from these different kinds of processing is combined and a spatial "priority map" of the visual field is created, which is a constantly evolving map that is used to guide selective attention to the most relevant place in the visual field. Some other factors also influence where attention will be guided, such as visual fixation. Attention will automatically be more likely to be guided towards a new relevant stimulus if this is close to the current visual fixation point. According to guided search 6.0, the search for a specific stimulus will terminate when a threshold is reached, also called the quitting threshold. This quitting threshold is not a set level, but adapts to the current search conditions (Wolfe, 2021).

Factors influencing visual search

Manipulating search tasks is a way to assess different aspects of visual attention (Davis & Palmer, 2004). Some manipulations are known to have effects on the efficacy of visual search in participants. An example of this is a study that found that the less prevalent a target was in a search task, the more likely participants are to miss it. This means that participants were found to be more accurate in identifying a target if it appeared frequently (Wolfe et al., 2005).

Additionally, Treisman and Gelade (1980) found that reaction times are longer in conjunction searches when there are more distractors. This effect has been replicated many times, and a linear relationship between increased set size and rise in reaction time has been found (Wolfe, 2021). The same effect cannot be found for parallel searches using feature processing, where no reaction time increase is seen when set size increases (Treisman & Gelade, 1980).

Some demographic factors can also affect the performance of search tasks. For example, the age of a participant has been found to have an effect on the time it takes to find a target object in a search task, with older adults generally taking longer than younger adults (Hommel et al., 2004). This age-related slowing in reaction time is particularly seen when asking the participant to perform a conjunction search (Humphrey & Kramer, 1997). Furthermore, the previously described increase in reaction time seen in a task with more distractor objects has been found to be particularly evident for older adults. Older adults are more affected by the number of distractor objects than younger adults, causing older adults to have longer reaction times when there are more distractor objects in the visual search scene (Hommel et al., 2004).

Additionally, reading direction has been found to influence spatial search strategy. A study has found that readers who read from left to right, as most Western languages do, had a higher tendency to begin searching at the upper part of the screen as well as on the left part of the screen. This tendency was found when comparing literate lift-to-right readers to an illiterate control sample (Olivers et al., 2014). These results indicate that the ability to read and the direction of reading affect the visual scanning and visual search tendencies (Bramão et al., 2007).

Neuroanatomy of visual search

Researchers have previously attempted to answer the question of where the attentional systems that enable visual search are localized in the brain. A study by Luck and colleagues (1989) found that patients, who have had surgical transection of the corpus callosum could conduct a visual search task faster than their control subjects. This increased search speed is explained by the hemispheres being able to search independently of each other and in parallel. On the basis of this, they conclude that the attentional system employed in this search must be bilateral, in order for both hemispheres to conduct the search (Luck et al., 1989).

Previous research has investigated what areas of the brain are especially activated when a participant is asked to perform a visual search. It has been found that overt search tasks, such as the task used by Luck and colleagues, activate the dorsal frontoparietal attention network (Ischebeck et al., 2021). Since the dorsal frontoparietal network is organized bilaterally (Szczepanski et al., 2013), this is concurrent with the findings from Luck and colleagues.

Hybrid search

However, most of the time we are not only searching for our friend at the train station or for Waldo. Often people need to be able to search for more types of target stimuli simultaneously, for example when they are grocery shopping and need to search for several objects from our shopping list. One way to understand the more complex search performed in everyday life is by using hybrid search tasks. Hybrid search tasks are a combination of visual search and memory search, where participants are asked to search a visual display for one instance of several different possible targets that they are holding in their memory (Wolfe, 2012). In this way, the hybrid search paradigm combines selective attention and memory into one simple search task (Wiegand & Wolfe, 2020). The paradigm was first introduced by Schneider and Shiffrin (1977) and later expanded by Wolfe (2012), who argues that using a hybrid search task is a naturalistic way of assessing selective attention and long-term memory, since this task assimilates how we use these processes in our everyday life.

If the interaction between memory and visual search was linear, then hybrid search tasks, such as searching for items from a memorized grocery list at the store, would take a very long time. Instead, reaction times in hybrid visual search tasks are found to increase linearly with the number of distractor objects but increase logarithmically with the number of memorized target objects (Wolfe, 2012). This effect has been replicated in both younger and older adults (Wiegand & Wolfe, 2020).

A study by Wiegand and Wolfe (2020) has found that although there is a general slowing in reaction time with age, there is no age-related decline in the ability to conduct a hybrid visual search, or the attention and memory processes that are used to do this. They found that their sample of older adults had longer reaction times than their sample of younger adults, but that the relationships between reaction time and visual set size as well as between reaction time and memory set size were similar across age groups (Wiegand & Wolfe, 2020).

Foraging search

Other times, instead of searching for one instance of several target types, everyday life requires people to search for several instances of a single target type. An example of this could be when looking for all the instances of a specific type of Lego brick in a box full of Lego. This led to the development of another way of mimicking the complexity of visual search in everyday life in a laboratory search task. In this task, called the foraging search task, participants search visual displays for multiple instances of a single target type (Wolfe et al., 2016). This foraging search paradigm is based on the assumption that human foraging is very similar to that of other species of animals (Kristjánsson et al., 2014). This means that the search patterns we see in foraging search are very similar to how food is found in nature (Wiegand & Wolfe, 2021). When foraging, people are able to find the next target object, even before they have collected the current target object. It has been found that people are typically able to forage one or two target objects ahead (Kosovicheva et al., 2020).

Optimal foraging behavior.

In the foraging paradigm, human visual search is often compared to picking berries. In this analogy, the person searches a bush for berries to pick. The person can at any point choose to leave the current berry bush and find the next one, although this act would include some travel time from one berry bush to the next. When collecting ripe berries from a bush, each berry that is collected is one less berry on the bush. At some point the number of berries left on the bush will be low enough that it will begin to require more searching in order to find the next ripe berry. In these cases, knowing when to leave the current berry bush and travel to the next one can be an advantage, as this would allow the forager to maximize the amount of food they can find and minimize the time spent searching for the food. In a laboratory setting, the berry bush is a visual display called a patch, and researchers have attempted to predict when participants will choose to leave a patch and go to the next one (Wolfe, 2013).

The optimality of foraging behavior is completely dependent on the given situation. When leaving a patch, the participant must do an internal cost-benefit analysis to determine if the added travel time between patches, during which no berries can be picked, is worth it. If there is a long travel time between patches, it may make sense to stay longer on the current patch and search more exhaustively. On the other hand, if there is a short travel time between patches, it may make more sense to switch to the next patch faster when targets are becoming scarce in the current one. In this way, the foraging environment influences the optimal strategy for patch leaving (Wolfe et al, 2016).

Marginal Value Theorem.

One of the most influential ideas in the study of optimal foraging behavior in humans is Charnov's (1976) Marginal Value Theorem (MVT). MVT is a model of optimal patch leaving that is drawn from the animal foraging literature but is seen as representative of human foraging behavior as well (Ehinger & Wolfe, 2016). MVT attempts to model when a forager will choose to leave a patch in a given environment (Wolfe, 2013). The founding idea of MVT is that the optimal forager will try to maximize food intake and collection rate and will therefore choose to leave a patch when the instantaneous rate of collection drops below the average rate of collection for the whole field (Charnov, 1976; Wolfe, 2013). This means that human foraging behavior can be evaluated through MVT, by calculating the most optimal time to leave a patch using the current picking rate, the average picking rate, and the travel time between patches (Wolfe, 2013). An illustration of this calculation is shown in Figure 1.

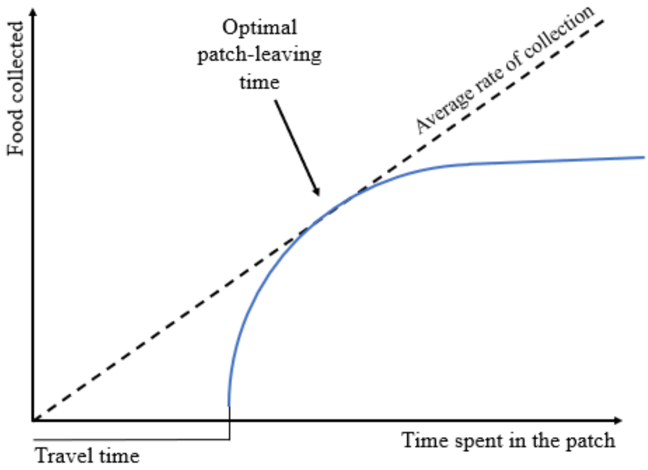


Figure 1. Illustration of Marginal Value Theorem. The horizontal axis represents the time spent in a given patch while the vertical axis represents the food or targets collected in the given patch.The dashed line represents the average rate of collection for the whole field or environment, meaning the average rate of food collection per unit of time spent in the patch. When moving to a new patch there is a travel time between patches before foraging can begin. The blue curve represents the foraging activity of a person looking for food or targets in the patch. In the beginning, the amount of food collected from the patch increases rapidly, but food collection will gradually slow down as the patch is emptied. The optimal forager will leave the patch when the instantaneous rate of collection, meaning the slope of the blue curve, is smaller than the average rate of collection.

One criticism of MVT is that the theorem assumes that the forager knows the instantaneous rate of collection and the average rate of collection, in order to make the internal cost-benefit analysis (Wiegand & Wolfe, 2021). Another assumption of MVT is that it assumes that all patches are the same, with a predictable number of targets and a predictable travel time. Wolfe (2013) investigated this and found that the foraging behavior predictions by MVT held up in simple foraging situations with identical patches, but when foraging became more complex, as it often is in naturalistic settings, the foraging behavior that was observed deviated from the predictions made by MVT. The conclusion of the study was that the predictions of MVT are a good fit to human foraging behavior, when the patches are uniform in quality (Wolfe, 2013).

Hybrid foraging search

However, in their everyday life people are often required to search in an even more complex manner. For example, if someone drops a handful of coins in the street, it is relevant for them to search for all instances of all the different types of coins. In order to have the search paradigm resemble everyday life as closely as possible, researchers have combined the hybrid search paradigm with the foraging search paradigm, creating the hybrid foraging search task (Kristjánsson et al., 2020; Wolfe et al., 2016). In the hybrid foraging search task participants forage for multiple instances of multiple different target types (Wiegand & Wolfe, 2021). As in the foraging paradigm, participants performing hybrid foraging tasks search a patch for instances of their target objects and can choose to travel to the next patch at any time (Wolfe et al., 2016). It has been found that performing a hybrid foraging task involves higher levels of attention and executive function than when a simple visual search task is performed (de Liaño et al., 2018).

Some research has been conducted investigating what factors influence the choices participants make when performing a hybrid foraging task (Wiegand et al, 2019; Wiegand & Wolfe, 2021; Wolfe, 2013; Wolfe et al., 2018). One aspect that has been researched is what factors influence which target object is picking in a hybrid foraging search task. It has been found that the selection of a target object is not random since it relies largely on the previously selected target object. In hybrid foraging tasks, where the frequency and value of the different target object was similar, participants were likely to search the patch in “runs”, focusing first on picking several instances of one target object type before switching to another target object type (Kristjánsson et al., 2014). This is thought to be a more effective way of searching, since switching between different target object types takes time (Wolfe et al., 2019).

Which target object is picked is also influenced by the prevalence of the target objects. If the prevalence of the different target types in a patch is not equal, it has been found that participants showed above chance preference for picking the most prevalent target types (Wolfe et al., 2018). Additionally, the choice of picking a target object is also influenced by the target value of each object. The target value reflects how much reward is gained for picking the target object, such as points or food intake. If target objects differ in value, then participants are more likely to pick the highest valued target objects (Wiegand & Wolfe, 2021; Wolfe et al., 2018). However, when there is both varying target value and varying target prevalence, the selection preference seems to vary between individuals, with some choosing the most valuable targets first while others choose the most prevalent targets. For younger adults, the tendency to avoid selection of low-value targets, and instead prefer selecting high-value targets has been linked to a measure of reward-seeking behavior (Wiegand & Wolfe, 2021).

Another aspect that has been researched is how the hybrid foraging task is affected by aging. Wiegand and colleagues (2019) have assessed the optimality of foraging in a hybrid foraging task for both younger adults and older adults. The foraging patterns for both age groups were compared to the foraging predictions made by MVT, and an age-related decline in optimal foraging behavior was found. The study found that while the younger adults' foraging behavior was similar to the predictions made by MVT, the older adults stayed longer in the patches and foraged more exhaustively in each patch (Wiegand et al., 2019). The study also found that while there was a general slowing of reaction time with age, there were no age-related deficits in memory or attention on the hybrid foraging task. Additionally, the effects of visual set size and memory set size and the cost of switching between target types was comparable between the two age groups. These findings are in line with the previously mentioned research on hybrid search, which found that there is no age-related decline in the memory and attention processes needed to conduct a hybrid visual search (Wiegand & Wolfe, 2020). On the basis of these findings, the study concluded that the cause of the age differences in the hybrid foraging task was not a decline in cognitive functions, but rather an age-related difference in search strategy (Wiegand et al., 2019).

Visuospatial neglect

As evident from the previous sections, the different aspects of visual attention are integral parts of our daily lives and the way that we perceive the world. The following sections will explore what happens when there are deficits in visual attention. The sections will focus on the most common of these deficits in visual attention, namely visuospatial neglect (Breedlove & Watson, 2017).

History of neglect

Descriptions of deficits in visual attention in patients can be traced back to the late 19th century (Halligan & Marshall, 1993). The term neglect was first used to describe the deficits by Hermann Pineas in 1931, where he used the German word *vernachlässigung* (translated to neglect) to describe how a patient was neglecting to attend to an entire side of her visual field (Pineas, 1931). In these early descriptions, neglect was not considered a syndrome in itself, but only described as one of several symptoms of a larger disturbance (Halligan & Marshall, 1993).

It was not until the second world war that Russell Brain in 1941 described neglect as a separate syndrome. Brain was the first to describe the main characteristics of neglect in isolation (Halligan & Marshall, 1993). Brain also described defects in spatial awareness in his patients with neglect that could not be explained by visual field defects (Brain, 1941).

Definition of neglect

The main symptom of visuospatial neglect is being unresponsive and unaware of either the right or left side after an injury to the brain. While visuospatial neglect can affect both sides, it most often presents as inattention to the left visual field and is often detected when patients don’t respond to people or objects to the left of their midline (Breedlove & Watson, 2017).

An important caveat is that the failure to respond to one side must not be explained by other sensory or motor defects, such as visual field defects (Heilman et al., 1984). Neglect must instead be understood as an attentional disorder. This has been demonstrated by an ingenious study by Bisiach & Luzzatti (1978), where they asked patients with neglect after right hemisphere brain injury to describe a very familiar piazza in Italy. They found that if asked to form a mental image of the piazza as if they were standing at one end of it, the patients would describe all the shops and buildings only on the right side, while omitting details from the left side of the piazza. The results of this study demonstrate that neglect is not simply a disorder of visual perception, but also a disorder of representational space and mental imagery (Bisiach & Luzzatti, 1978).

Another way to distinguish neglect from a purely sensory disorder, is that the borders for the neglected area are moveable, unlike what you would see with a sensory deficit such as a visual field deficit. In neglect, it is possible to move the borders of the neglected areas somewhat, by asking participants to actively focus on that area (Heilman et al., 1984).

Distinctions in neglect

When working with neglect, it is necessary to distinguish between the different facets. In general, neglect can be understood as having three different dimensions: the processing stage, the reference frame, and the spatial sector (Pitteri et al., 2018). Neglect is attributed to deficits in either the motor-intentional, sensory-attentional, or representational processing stage. The failure to put your arm into the left side of your shirt or shave the left side of your face would be a sign of motor-intentional neglect, whereas the failure to form the left side of mental representations, such as in the study by Bisiach and Luzzatti (1978) would be an indicator of representational neglect. If instead, the patient is unable to allocate attention to the left side of their visual field or otherwise unable to attend to sensory input from the left side, this would be an example of sensory-attentional neglect (Na et al., 1998). Sensory-attentional neglect can be seen for all sensory modalities and can occur in one or more modality in the same patient (Pitteri et al., 2018). When sensory-attentional neglect affects the ability to attend to visual stimuli, it is often termed visuospatial neglect (Halligan et al., 1989).

Another dimension of neglect is the reference frame. In this dimension, neglect can be seen as either egocentric or allocentric. Egocentric neglect is also known as space-based neglect, as is seen when patients do not attend to one side of space on either the left or right side of the patient's own body midline. Egocentric neglect appears to be the most common of the two types. Allocentric neglect, or object-based neglect, is when patients fail to attend to one side of all objects. The unattended side of the object is the contralesional side and is typically the left side. Although some patients have both egocentric and allocentric neglect, a double dissociation between the two has been found, meaning that some patients have allocentric neglect without egocentric and vice versa (Demeyere & Gillebert, 2019).

The final dimension of neglect is the spatial sector (Pitteri et al., 2018). In this dimension, neglect can be either personal or extrapersonal. When it is neglect of the person's own body, then it is classified as personal neglect, whereas neglect of areas outside of the body, such as in the visual field, is called extrapersonal neglect (Bisiach et al., 1986).

Patients with neglect often think that they have an appropriate representation of their environment. This is a result of anosognosia commonly co-occurring with neglect, resulting in denial and minimization of the deficits. Anosognosia is a term for when a person lacks insight and awareness of their impairments. Neglect with anosognosia increases the risk of accidents, such as falls (Grattan et al., 2018). Lacking awareness of their neglect has also been found to negatively affect the rehabilitation process after their brain injury (Gialanella et al., 2005).

Something that is often seen alongside neglect is the extinction phenomenon. Extinction is defined as the inability to report observing a stimulus in the contralesional field, when a stimulus is presented in the ipsilesional field at the same time, despite reporting the stimulus in the contralesional field when it is presented by itself. Extinction can be seen for the auditory, visual, and tactile modalities, and can also travel across modalities, meaning that an object in the ipsilesional visual field can cause extinction for touch on the contralesional side of the body (Driver & Vuilleumier, 2000). Many patients suffering from neglect also present with extinction, but not all neglect patients. Similarly, extinction can be found in patients who have no history of neglect. This double dissociation between neglect and extinction indicates that, while the two are often comorbid, neglect and extinction should be understood as separate disorders. Extinction in itself can be hard to assess clinically, as this is easier for patients to compensate for in the testing than neglect (Bonato, 2012).

Neuroanatomy of neglect

Neglect is commonly seen after injuries to the brain, including strokes (Gottesman et al., 2008). The neglected side is often the side contralateral to the hemispheric lesion (Na et al., 2000). Neglect can be seen for both left and right hemisphere lesions but is most commonly seen after damage to the right hemisphere, resulting in left-side neglect (Gainotti et al., 1972). There is some uncertainty in the reported prevalence of neglect, with reports varying from 13% to 82% of patients with right hemispheric lesions presenting with neglect (Bowen et al., 1999). This variability in prevalence may be a result of different studies using different assessment methods to diagnose neglect, different inclusion and exclusion criteria and participant groups with differing time from lesion onset (Azouvi et al., 2002).

Another factor that could affect the prevalence is the age of injury onset, with the prevalence of neglect after brain injury being higher in older adults. One study found that 69.6% of patients who were 65 years or older at injury onset developed visuospatial neglect, while only 49.4% of patients who were under 65 were found to have neglect. This is hypothesized to be a result of age-related brain atrophy, causing the older patients to have more difficulties compensating for the injury (Gottesman et al., 2008).

There is no one singular area, in which lesions are associated with neglect. Traditionally, neglect has been associated with lesions to the right parietal lobe, with the symptoms typically being more severe if the temporoparietal junction is injured (Vallar & Perani, 1986). Frontal injuries, such as lesions to the right inferior frontal lobe, have also been known to result in neglect (Mort et al., 2003). It has also been found that lesions to subcortical areas, such as the thalamus and basal ganglia, can cause neglect, although it has been suggested that the neglect is an indirect result of this injury, caused by the resulting reduction in blood flow to the overlying cortical areas (Hillis et al., 2002).

When averaging the injuries of many people with neglect, a lesion map can be created to show the average lesions resulting in this deficit. This lesion map has been found to fit with the frontoparietal networks of attention (Breedlove & Watson, 2017). It has been argued that neglect should be understood as an impairment of this attention network, rather than a specific focal lesion (Mesulam, 2002). However, within this frontoparietal attention network, it has been hypothesized that lesions in the posterior part of the network are associated with sensory-attentional neglect, while frontal lesions are associated with motor-intentional neglect (Na et al., 1998).

Assessment of visuospatial neglect

Neglect is a debilitation deficit that is associated with longer length of hospitalization (Appelros, 2007) and unsafe navigation, such as bumping into objects when walking (Tromp et al., 1995). Therefore, it is important to know if a patient suffers from neglect, in order to ensure their safety. Spatial neglect has been reported to be underdiagnosed and underdocumented, especially if the neglect is not severe (Chen et al., 2013). This highlights the need for clinical assessments of neglect, that are also able to measure mild and moderate cases of neglect in patients.

There are many different ways of testing for neglect, with one literature review finding 28 standardized and 34 non-standardized neglect assessment tools (Menon & Korner-Bitensky, 2004). These different tests also assess different aspects and dimensions of neglect, with some testing for egocentric or allocentric neglect, some testing for motor-intentional, representational, or sensory-attentional neglect and others testing for personal or extrapersonal neglect (Demeyere & Gillebert, 2019; Menon & Korner-Bitensky, 2004). However, using different neglect assessments will often lead to different results (Grattan & Woodbury, 2017).

Paper and pencil tests

The traditional method used to assess visuospatial neglect is by using paper-and-pencil tests. In this kind of testing, patients are asked to fill out or perform a task given on a piece of paper (Lezak et al., 2012). One commonly used example of this is asking the participant to copy familiar objects by drawing them on the piece of paper. Specifically, patients suspected of having neglect are often asked to draw the numbers on the face of a clock or to copy a simple figure such as a house or a star. For patients suffering from neglect, this will typically result in imbalanced drawings, where all of the numbers on the clock are arranged only on the right side of the clock, or where only the right side of the house or star is copied in their drawing (Halligan & Marshall, 1993).

Another way of testing for neglect using paper-and-pencil tests is by asking the patient to perform a line bisection task. This is done by giving the participant a sheet of paper with a number of horizontal lines drawn and asking them to mark the midpoint of the lines using a pencil. What is typically seen for patients with neglect is that they will mark the midpoint of the lines to the right of where the true midpoint is. Line bisection tasks are scored by measuring the length by which the patient's midpoint deviates from the true midpoint (Ishiai et al., 1998).

Cancellation tasks are also a commonly used method to assess for neglect. Here a patient is given a sheet of paper with target objects and distractor objects and asked to mark all target objects by crossing them out (Lezak et al., 2012). Some cancellation tasks, such as the Apples Cancellation Test also differentiate between egocentric and allocentric neglect and allow for assessment of both (Mancuso et al., 2015). Cancellation tasks are often scored by calculating how many omissions the patient made, meaning target objects that were not crossed out, as well as how many errors they made, meaning distractor objects that were erroneously crossed out. The criteria for what is within the normal parameters varied between different cancellation tasks, but is typically very low, with some tests allowing for only one omission and others accepting up to three (Mancuso et al., 2015; Vanier et al., 1990). Of the paper-and-pencil assessments, the cancellation tasks have been estimated to be the most sensitive assessment of neglect (Halligan et al., 1989).

An advantage of the paper-and-pencil assessments is that they are generally easy to administer and score as well as often readily available to use for clinical assessments. Unfortunately, one study found that the paper-and-pencil test detected visuospatial neglect in only half of their sample of twelve patients known to have visuospatial neglect. Most of the patients where the paper-and-pencil tests detected neglect were still in the acute phase of their rehabilitation (Grattan & Woodbury, 2017). While this study uses only a small sample, it demonstrates a trend that can also be found in other studies, and calls into question the stability of using paper-and-pencil tests in isolation (Barrett et al, 2006). Another support for using multiple tests to assess neglect comes from the double dissociation that has been found between cancellation tasks and line bisection tasks, with some patients being impaired in one task but not the other and vice versa (Ferber & Karnath, 2001).

However, the results on paper-and-pencil tests do not always correlate with the amount of difficulties a person has in their everyday life and how affected they are by neglect. Accounts of patients, who exhibit clear neglect symptoms in their daily life but perform within the normal range on paper-and-pencil tests, indicate it may be possible to compensate for neglect in these simple assessments, but not in complex situations, as those experienced in everyday life (Hasegawa et al., 2011). When these patients are instead tested using more complex testing assessments, they may no longer be able to compensate for their neglect and again demonstrate contralesional inattention. This highlights the need to use more complex, and consequently more sensitive assessment methods when testing for neglect (Bonato, 2012).

Functional assessment

It has been found that simply observing the behavior of a patient is more sensitive to registering neglect than classic neuropsychological testing using paper and pencil assessments (Azouvi et al., 2002). In a nationwide survey among relevant healthcare professionals, unstructured observations were the most commonly used method of assessing neglect in Denmark (Evald et al., 2021).

In order to structure the behavioral observations, functional assessment methods of neglect have been proposed. The aim of this form of assessment is to test the patient's performance in everyday life situations in order to evaluate how affected the patient is by neglect (Azouvi et al., 1996). Most functional assessments require the patient to attend to objects both close to the body, in the area around the body and in the area further away from the body (Grattan & Woodbury, 2017). Because functional assessments often have higher and more complex task demands, this may make it harder for patients to compensate for their deficits than when performing paper and pencil tasks (Bonato, 2012).

The most widely used functional assessment is the Cathrine Bergego Scale (CBS) (Pitteri et al., 2018). The CBS aims to measure the impact that neglect has on patients' everyday life by assessing how they function in everyday situations. The CBS is designed as a standardized checklist of specific daily activities to help healthcare providers assess the severity of neglect. The situation checklist includes assessing if the patient grooms the left side of their face, if they eat food from the left side of their plate, if they attend to noise from the left side, if they collide with objects on their left when moving around and six other situations, making it a total of ten situations that are assessed (Azouvi et al., 1996).

However, the reliability of the CBS is limited by the lack of specific observational context for each of the everyday situations assessed. This means that the score that a patient gets for their symmetry of personal grooming may vary, depending on who is assessing the patient (Chen et al., 2012). Additionally, the CBS assesses only neglect for the left side, disregarding right-sided neglect (Barrett et al., 2006). The CBS also requires control of both the upper and lower limbs in many of the everyday situations that are assessed, which may affect the applicability of the assessment method (Menon & Korner-Bitensky, 2004).

Computer-based assessment

As an alternative to the simple observations or paper-and-pencil tests, computer-based assessment methods of neglect are gaining popularity. These computer-based assessment formats allow for more control over the presentation of stimuli, as well as more precise reaction time measurements. Additionally, computerized assessments can better detect reduced processing speed and compare reaction times across the right and left visual field. For these reasons, computer-based assessments have been found to be a more sensitive measure of neglect than paper-and-pencil tests (Schendel & Robertson, 2002).

While computer-based assessment of visuospatial neglect is still gaining traction in the clinical settings, it has long been the standard practice in laboratory testing. For example, a simple computer-based conjunction search task has been used to study visual search in patients suffering from visuospatial neglect. Patients were instructed to search for a target object that could be shown on either the right or left side of the screen. A varying number of distractor objects would also be shown on the screen at the same time. The participants' reaction time before finding the target object was then measured. If there were no distractors shown on the ipsilesional side, the reaction time for locating the target when shown on the ipsilesional side was the same as when the target was shown on the contralesional side of the screen. However, if there were distractors on the ipsilesional side of the screen, then participants had a harder time finding the target object on the contralesional side. In fact, each distractor shown in the ipsilesional field was found to triple the search time before the target object in the contralesional field was found (Eglin et al., 1989). This study highlights the importance of having several distractors in the ipsilesional field when testing patients with visuospatial neglect, as this accentuates the deficits shown by the patients. It is also a good illustration of the advantages that come with using computer-based assessment of visuospatial neglect, as the specific reaction times and effect of distractors in the ipsilesional field would not be accessible for measurement using pen-and-paper testing methods.

Hybrid foraging as a bedside assessment tool for visuospatial neglect

The aim of this study is to develop a new way of assessing for visuospatial neglect that is challenging, available as a bedside test, and assesses a broad range of parameters. In cooperation with researchers in Denmark and the Netherlands, the hybrid foraging task has been suggested as a possible way of testing for visuospatial neglect that lives up to those criteria.

When measuring visual search, it has been suggested that using a hybrid foraging task instead of a simple search task gives us results that are more comparable to functioning in everyday life. The reason is that the types of searches that are done in everyday life are typically more complex than simply searching for a single instance of a single target object (Kristjánsson et al., 2020). Assuming that it is true that using a complex task, such as the hybrid foraging task, is a more realistic measure of visual attention in everyday life, then this should also be true for measuring deficits in visual attention such as visuospatial neglect.

Additionally, hybrid foraging tasks have been found to involve more attentional and executive functions than normal visual search tasks (de Liaño et al., 2018). Performing a hybrid foraging task necessitates selective attention, memory, inhibition, task switching, cognitive flexibility, and sustained attention (Muñoz-García et al., 2018; Wiegand et al., 2019).

In conclusion, the hybrid foraging paradigm is thought to be a good task for cognitive assessment, since it is a straightforward and naturalistic assessment method that combines measurement of many factors in an enjoyable game-like task (de Liaño & Wolfe, 2022; Wiegand et al., 2019). By adding a measurement of the spatial placement of clicks, the hybrid foraging task potentially becomes a very good assessment for visuospatial neglect. The hybrid foraging task is a complex task, with several target types and distractor types in both the ipsilesional and contralesional field. This potentially makes it able to detect both visuospatial neglect and extinction in patients. The hybrid foraging task combines the sensitivity of computer-based testing with a complex and demanding task.

General research design

In this study, the hybrid foraging task will be formatted for use on a touchscreen and a measure will be added, recording the spatial placement of each click on the screen. In order to potentially use the hybrid foraging task to assess visuospatial neglect, is it first necessary to know how a person without visuospatial neglect would perform on this task. In particular, it is necessary to understand where on the screen target objects would be collected by a control population, in order to later see if patients, who are known to have visuospatial neglect, will have differing patterns of target collection. Because of this, the present study will have a mostly exploratory approach in aiming to identify the patterns found in performance on a sample of neurologically healthy control participants.

This study consists of three experiments, where the following experiment will build on the findings from the previous experiment. All participants in this study will be 65 years old or older. This age group is chosen in order to make the results from this study comparable to the data previously collected on American participants using the hybrid foraging task (Wiegand et al., 2019; Wiegand & Wolfe, 2021). Furthermore, this age group is chosen because strokes are more frequent in older adults, with up to 70% of all strokes occurring in people who are over 65 years old (Kelly-Hayes, 2010). Visuospatial neglect is a common symptom after stroke and appears to be increasingly common with age (Gottesman et al., 2008). Because the aim is to eventually be able to use this hybrid foraging task as a tool to assess visuospatial neglect, it is relevant to understand the performance in the age group where the task is likely to be most frequently used.

Hypotheses

This study is first and foremost explorative, with the aim of investigating potential visuospatial patterns in the performance of healthy older adults on the hybrid foraging task. However, some results are expected to be found, and are necessary if the hybrid foraging task is to be used on a tablet as a bedside tool for assessment of visuospatial neglect. This led to two hypotheses, which will be investigated throughout the three experiments in this study. The first hypothesis is that the hybrid visual foraging can be used on a touchscreen tablet and thereby be made available for bedside testing. This entails ensuring that the user interface is appropriate for the age group of people over 65 years, as well as examining if alterations are needed to either the task or the instructions. The second hypothesis is that the neurologically healthy participants will disperse their attention almost equally throughout the screen on the hybrid visual foraging task. While it is expected to find a slight bias in search tendencies, as predicted by the research on the effect of reading-direction, it is not expected that there will be any major gaps in object collection throughout the screen.

Additionally, previous research using the hybrid foraging task gave rise to a third hypothesis regarding the generalization of performance on the hybrid foraging task across nationalities. The third hypothesis is that the data collected on the sample of older Danish adults corresponds to data from previous research on participants in a similar age group from America.

This means that, given their age group, the participants in this study are not expected to search optimally as measured by MVT. Furthermore, this means that the general pattern of foraging behavior found in previous research using the hybrid foraging task can be replicated in a sample of older adults in Denmark, including when they choose to leave a patch, how many target objects they leave uncollected when leaving a patch and how many distractor objects they incorrectly collect.

Ethical considerations

No ethical approval was required for the studies done in this project. The data collection was collected in accordance with the Declaration of Helsinki (1964) and complied with GDPR rules. Prior to their participation, written informed consent was obtained from all participants. The participants were identified using anonymized participant identification numbers.

Experiment 1

This study is the first time that this hybrid foraging task has been made available for bedside testing by using a tablet with a touchscreen. In order to ascertain if the hybrid foraging task is appropriate to use on a tablet, the aim of this first experiment was to assess the testing process and evaluate if alterations needed to be made before testing on a larger sample. Furthermore, this experiment aimed to explore if any distinct patterns in performance on the hybrid foraging task could be identified in this small sample of participants.

Participants

Data was collected from two participants. Participant 1 was a 68 year-old female and Participant 2 was a 65 year-old male. Both participants had normal or corrected to normal visual acuity. Both participants reported no previous neurological issues, and while no formal assessment of this was done, it has previously been found that relying on the participants to self-report neurological disorders is an adequate screening process (Stanczak et al., 2000). Participation in this study was voluntary and did not entail monetary compensation.

Stimuli and apparatus

The task used to assess hybrid foraging search is the one first described by Wolfe and colleagues (Wolfe et al., 2016). This task uses stimulus items of everyday objects selected from a database of 1,922 objects (Brady et al., 2008; Wiegand et al., 2019). From this, eight unique target objects are selected at random to be used for each participant. An example of eight selected target objects is shown in Figure 2:

Figure 2. An example of a target object set used in this task.

The hybrid foraging task was performed on a Lenovo MIIX 320 10.1" 2-in-1 tablet with a detachable keyboard. The keyboard was detached when the participants were performing the search task. The task was performed while the tablet was held in landscape mode. The participants held the tablet themselves and therefore viewing distance could not be controlled for.

After the participants had performed the hybrid foraging task, they were interviewed about their experience of the task. This interview was performed according to the semi-structured interview guide (see Appendix A) and recorded using an Olympus WS-852 Digital Voice Recorder.

Procedure

In the task used here, participants searched for multiple instances of multiple target objects in patches where there were also distractor objects. Participants were tested outside the laboratory on a touchscreen table. First, participants were presented with their target objects. The target objects were shown individually on the screen for two seconds each. Eight unique target objects were used in this task (see example in Figure 2). After the target objects had been shown, participants were asked to perform a recognition test to assess their memory of the target objects. An object was shown on the screen and participants had to choose if this was one of the target objects that they had been presented with or a new distractor object. Participants chose "old" or "new" by pressing the corresponding button on the touchscreen. During the recognition test, all eight target objects were shown, along with eight distractor objects. The presentation of the target objects and the recognition test are illustrated in Figure 3. Participants were required to correctly recognize 90% of the objects as either a target or a distractor. If a participant failed to correctly recognize 90% of the items, they would again be shown their target objects as before and given the recognition test again. There was no limit for how many times a participant could go through this cycle before getting 90% correct and continuing the task, however both participants in this experiment were able to correctly recognize the targets in the first test and did not repeat the recognition test. The recognition test was done to ensure that participants were able to remember the target items in the following search tasks (Wiegand et al., 2019).

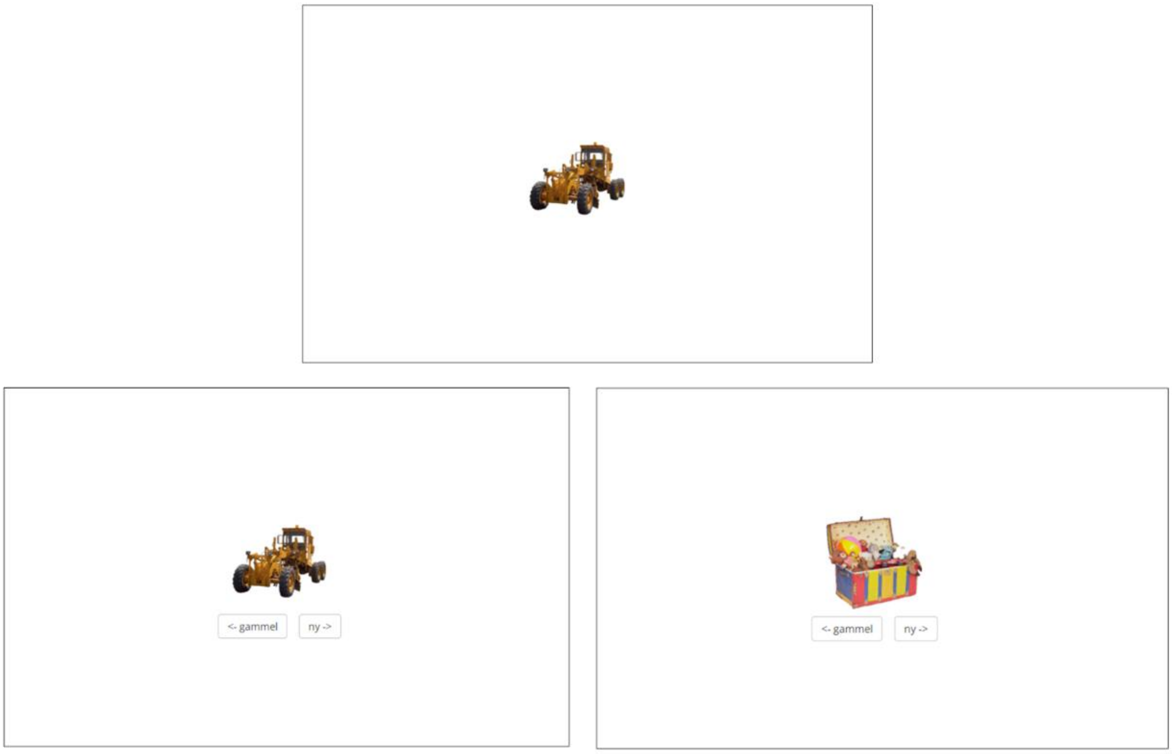


Figure 3. An illustration of the presentation of targets and the recognition task. The task begins by presenting the participant with the eight target objects chosen for their task. The target objects are shown individually on the screen for 2000 ms each (illustrated by the top image). Then the participant is presented with a recognition task where they are shown their 8 target objects as well as 8 novel distractor objects (illustrated by bottom images). The objects are presented individually, and the participant is asked to choose whether the shown object is an "old" (gammel) object, meaning one of the eight target objects they were previously shown (illustrated by bottom left image), or a "new" (ny) distractor object that they have not seen before (illustrated by bottom right image). Figure size relative to the screen size has been enlarged in this illustration for clarity.

After completing the recognition task, participants moved on to the hybrid foraging task. In this task, the participants had to search a visual display, here called a patch, for their target objects among a number of distractor objects. At the beginning of a new patch there was a visual set size of either 50 or 100 objects in total, including both targets and distractors. Examples of the two visual set sizes are shown in Figure 4. Which visual set size was used was determined randomly for each patch (Wiegand & Wolfe, 2021). Out of the total amount of objects shown in a patch, 30% of these were target objects and 70% were distractor objects. There were three different target objects shown in all patches regardless of the visual set size. All of the objects were moving around the screen at a speed of 50 px/s.

The goal of the task was to collect 500 points in each block of the study. There were two blocks in total. Participants collected points by clicking on their target objects. If they correctly pressed a target object, they would receive two points. If they incorrectly clicked a distractor object, one point would be subtracted from their score. An incorrectly clicked distractor object will be referred to as a false alarm. When a participant clicks on an object, they receive feedback on whether this was a target object or a distractor object. This feedback is illustrated in Figure 5. When a participant clicked on a target object by tapping it on the touchscreen of the tablet, it was removed from the patch. If a participant erroneously clicked on a distractor object, the object would be marked red as feedback that this was not a target object. It is important to note that participants did not need to collect all target objects from a patch. Participants moved to the next patch by clicking a “next” button on the screen, which they could choose to do at any time. The act of moving to the next patch is illustrated by Figure 4. When moving to the next patch, a travel time of either one second in the first block and three seconds in the second block was added before the new patch was shown on the screen. When a participant collected 500 points, a pause screen would be shown before beginning the second block. The second block was identical to the first, and also ended when participants had collected 500 points. After the second block, the task was done.

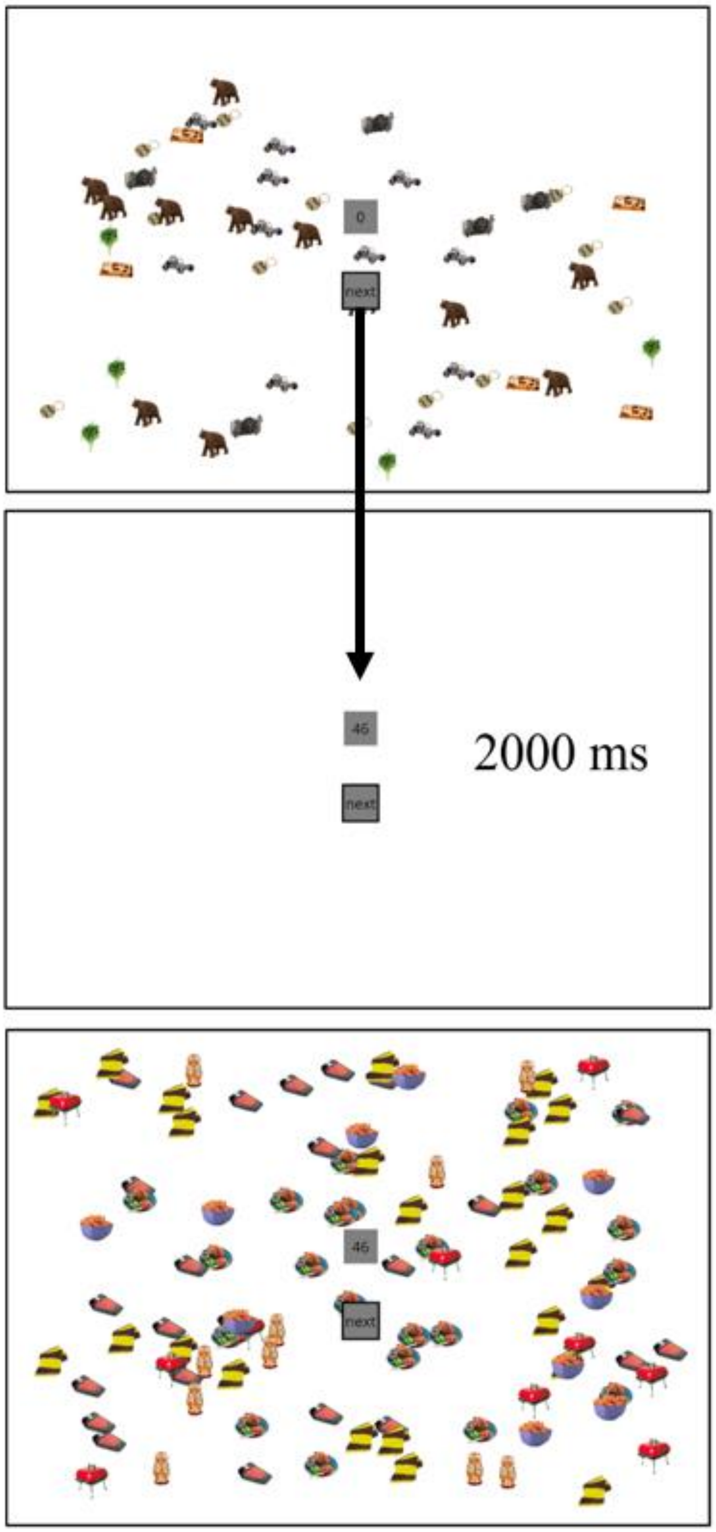


*Figure 4***.** Example of patch switching using screenshots from the hybrid foraging task. The screenshots show a patch with a visual set size of 50 objects (top picture) and a patch with a visual set size of 100 objects (bottom picture). The current number of points accumulated is shown in the middle of the screen and changes every time points are earned or lost. Moving to the next screen is done by clicking the next button. when doing so, a blank screen shown for 2000 ms represents the travel time between patches. This travel time is illustrated by the middle picture of a blank screen. After 2000 ms, the next patch is shown automatically.

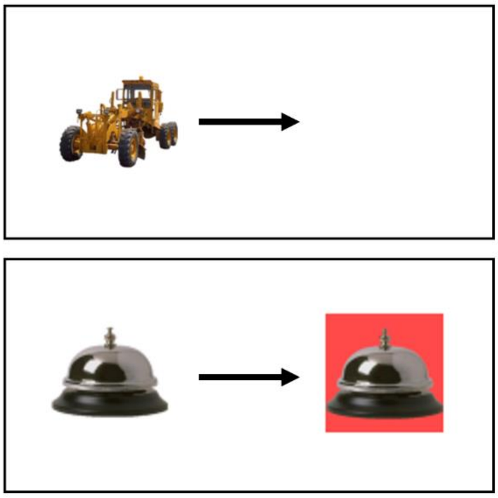


Figure 5. Illustration of feedback on target collection. The top picture shows that when clicking on a target object, the object will disappear from the screen. The bottom picture shows that when clicking on a distractor object, the object will flash red to show that this was a false alarm.

After the task was finished, the participants were interviewed about their experience of the task. This was done in order to ascertain if there were aspects of the hybrid foraging task that would benefit from being changed, in order to optimize the test for visuospatial neglect assessment. The participants were interviewed using a semi-structured interview guide (see Appendix A) and interviews were recorded in order to transcribe the answers. During transcription, the interviews were anonymized and when they had been transcribed, the voice recordings of the participants were deleted. During the interviews, the participants were asked to describe the task that they had just performed. They were also asked about potential strategies that they used during the task, as well as about their experience of the hybrid foraging task. Participants were asked broad questions, as well as questions specifically asking for their experience of the size of the tablet screen, the size and movement of the objects in the hybrid foraging task, the instructions to the task and their own ability to use touchscreen technology.

Results

Because there were only two participants in this experiment, all data will be looked at for each participant individually. For all analysis, the first and last patch of each block was excluded. The first patch of each block was excluded to give the participants a chance to develop a foraging strategy. Similarly, the last patch of each block was excluded because this patch ended when the participants reached 500 points, and they therefore did not actively choose when to leave this patch.

Descriptive

In a hybrid foraging task, where participants can choose when to move to the next patch, it is relevant to note that the two participants visited a different number of patches. Participant 1 visited 28 valid patches in the first block and 18 valid patches in the second block of the task. Likewise, Participant 2 visited 11 valid patches in the first block and 14 valid patches in the second block. It is also important to note, that the number of targets, that the participants leave behind uncollected when moving to the next patch also differs between the two participants, with the Participant 1 leaving an average of 11,68 targets behind in the first block and 7,39 targets in the second block, while the Participant 2 left an average of 4,91 targets behind in the first block and 5,93 targets when moving to the next patch in the second block.

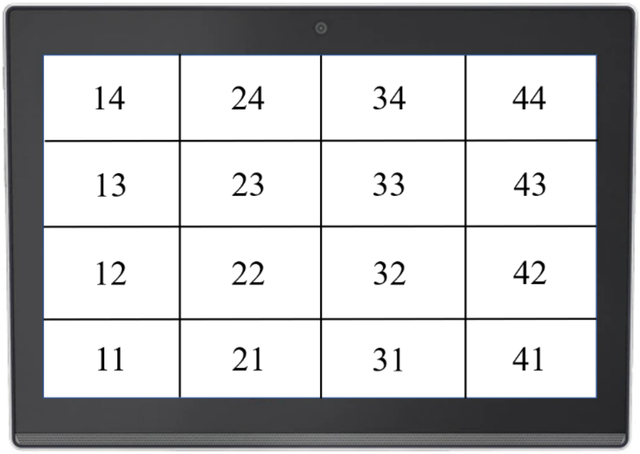


Figure 6. Illustration of the 16 sections of the tablet screen. The different sections are shown on a picture of the Lenovo tablet used for the hybrid foraging task. The screen was split into four equal sections on the horizontal axis (10, 20, 30 and 40) and four equal sections on the vertical axis (1, 2, 3 and 4). This produces 16 sections of the screen, each of which is denoted by the sum of the horizontal and vertical axis. Each collected object in the hybrid foraging task was placed in one of these 16 sections of the screen.

The number of false alarms in the valid patches was also recorded. False alarms are the incorrectly clicked distractor objects, which may be relevant to investigate in a potential visuospatial neglect assessment tool. It was also recorded where on the screen these false alarms were clicked. This data was given as a set of coordinates. In order to simplify and quantify these coordinates, they were split into four sections on the horizontal axis and four sections on the vertical axis, which created 16 sections of the screen (see Figure 6). Each false alarm was then placed in one of the 16 sections. After this analysis, the false alarms were excluded from the rest of the calculations. The placement of each false alarm was calculated and is shown for each participant in Figure 7. In order to compare the false alarms across participants and with previous research, the false alarm rate was calculated for each participant. The false alarm rate is a measure of the ratio between false alarms and all clicks performed in a patch. For Participant 1, the false alarm rate was 0,11 and for Participant 2 the false alarm rate was 0,02. After this, the false alarms were excluded from further analysis.

Participant 1:

1	5	8	1
5	6	11	2
6	5	4	4
1	5	3	2

Participant 2:

0	0	0	0
0	2	0	0
1	3	2	0
0	0	0	0

Figure 7. The spatial placement of each false alarm for Participant 1 (left) and Participant 2 (right). Each table should be understood as an image of the tablet screen, on which the participants performed the task. The amount of wrongly collected objects is presented for each of the 16 sections of the screen.

Using the same division of the coordinate field, the frequency of valid clicks for each of the sections was then investigated. This was a way of quantifying the distribution of clicked targets across the screen. Because the total amounts of valid clicks vary between the participants, the percentage of valid clicks in each section was calculated in order to make it comparable across participants. This illustrates how many percent out of the total amount of targets clicked, were collected in each section of the screen (Figure 8).

Participant 1:

3,8	5,8	5,0	3,0
9,4	8,8	9,8	3,8
8,2	14,6	13,2	3,8
1,4	4,0	4,8	0,6

Participant 2:

1,3	2,2	1,9	1,5
6,3	14,7	12,5	4,3
5,4	18,1	12,5	4,3
2,8	6,7	4,8	0,6

Figure 8. The spatial placement of valid clicks for Participant 1 (left) and Participant 2 (right). The percentage of all valid clicks that were done in each section of the screen is shown. Each table represents the surface of the tablet on which the hybrid foraging task was performed.

Additionally, the mean time per click was also calculated for each section (Figure 9). This time per click is measured in milliseconds and because the false alarms have been excluded from the dataset, the measure of time per click can be understood as a measure of time per collected target object. Examining the average time per collected target object for each section of the screen gives an impression of how the reaction time differs for different sections of the screen. Because of the limited amount of data in this experiment, further analysis on the differences between the sections of the screen will not be performed. When simply looking at the data presented in Figure 9, it appears that the reaction times for Participant 1 is lowest near the bottom edge of the screen, while the reaction times for Participant 2 seem to be more randomly distributed throughout the screen.

Participant 1:

2879,42	2398,83	2247,89	1607,95
1988,62	2194,74	1829,35	2134,27
1777,37	1633,15	1832,42	1997,51
1390,51	2324,48	1178,40	1175,07

Participant 2:

1169,97	1068,97	725,49	1065,37
1268,42	938,35	1019,01	1115,76
1193,64	1033,04	895,68	827,27
986,68	679,21	923,92	869,47

*Figure 9***.** The average time per collected target object for each section of the screen (ms per object). The average collection time for Participant 1 is shown on the left and the average collection time for Participant 2 is shown on the right. The collection time for all items in a section is averaged and presented here in milliseconds. Each table represents the surface of the tablet, on which the task was performed, and is split into 16 sections. Each section's placement in the table represents where on the screen it is placed.

Optimal foraging behavior

In order to evaluate if each participant forages optimally according to MVT, first it is necessary to calculate the instantaneous rates of collection as well as the average rate of collection for the whole patch. In all of these calculations, both the invalid patches, meaning the first and last patch of each block, and the false alarms are excluded.

The average rate of collection is a measure of how many points on average are collected per second across all valid patches in the task. The equation used to calculate the average rate of collection is presented in Equation 1. To calculate the average rate of collection, the total number of points collected within the valid patches are divided by the total amount of time spent on the valid patches (sum of time spent in patches plus sum of travel time between patches). The average rate of collection is calculated for each block separately (Table 1).

$$Average\ rate\ of\ collection = \frac{Total\ points\ in\ valid\ patches}{(Sum\ of\ time\ spent\ in\ patches + Sum\ of\ travel\ time\ between\ patches)} \tag{1}$$

$$Instantaneous\ rate\ of\ collection = \frac{Point\ value\ of\ each\ target\ object}{Average\ time\ per\ reverse\ click} \tag{2}$$

Next, the instantaneous rate of collection is calculated. The instantaneous rate of collection is found by taking the point value of each target and dividing it by the average time per reverse click. The equation to calculate the instantaneous rate of collection is shown in Equation 2. Because there are different amounts of clicks in each patch, looking at reverse clicks is a way to compare data across patches (Wiegand & Wolfe, 2021). Reverse click 1 is the last collected object in the patch before the participant decides to move to the next patch. Reverse click 2 is then the second to last collected object in the patch and so on. The instantaneous rate of collection will be calculated up to reverse click 5. This is done because the participants in this study are not expected to forage optimally given their age group, and therefore it is relevant to include several reverse clicks in the calculation to understand when the participants' instantaneous rates of collection drop below their average rate of collection.

In order to calculate the instantaneous rate of collection for each participant, first the mean time per reverse click must be calculated. The patches are split into the two blocks, so we get an average reaction time for reverse clicks in each block. Additionally, the patches are also divided by their visual set size, so we look at average reaction time for reverse clicks in each set size in each block. It is relevant to look at visual set size because more objects moving around the screen may make it more difficult for a person with visuospatial neglect or extinction.

Using the average time per reverse click, the instantaneous rate of collection can be calculated. If the participant forages optimally according to MVT, then they should leave the patch when their instantaneous rate of collection falls below their average rate of collection, which means that only reverse click 1 should be under the average rate of collection. See Table 1 for calculated instantaneous rates compared to the average rates. The relationship between the average rate of collection and their instantaneous rate of collection is shown in Figure 10 for each participant's two blocks.

Rates of collection for Participant 1:

	AR	VSS50 IR1	IR2	IR3	IR4	IR5	VSS100 IR1	IR2	IR3	IR4	IR5
Block 1	1,14	1,01	0,70	1,08	1,14	0,61	0,63	0,95	0,87	0,85	2,25
Block 2	0,48	1,18	1,10	0,78	1,05	1,46	0,54	1,00	1,79	1,42	1,39

Rates of collection for Participant 2:

	AR	VSS50 IR1	IR2	IR3	IR4	IR5	VSS100 IR1	IR2	IR3	IR4	IR5
Block 1	1,55	1,09	1,19	1,15	1,31	1,26	0,86	1,69	0,87	0,85	2,25
Block 2	1,67	1,62	2,31	2,77	3,08	2,55	1,28	4,21	2,11	2,35	3,14

Table 1. Average rate of collection and instantaneous rate of collection. All calculations are shown for Participant 1 (top) and Participant 2 (bottom) separately. Both the average rate of collection (AR) and the instantaneous rate of collection (IR) is calculated for each block separately. The instantaneous rate of collection is calculated for the last five reverse clicks for each of the two visual set sizes (VSS).

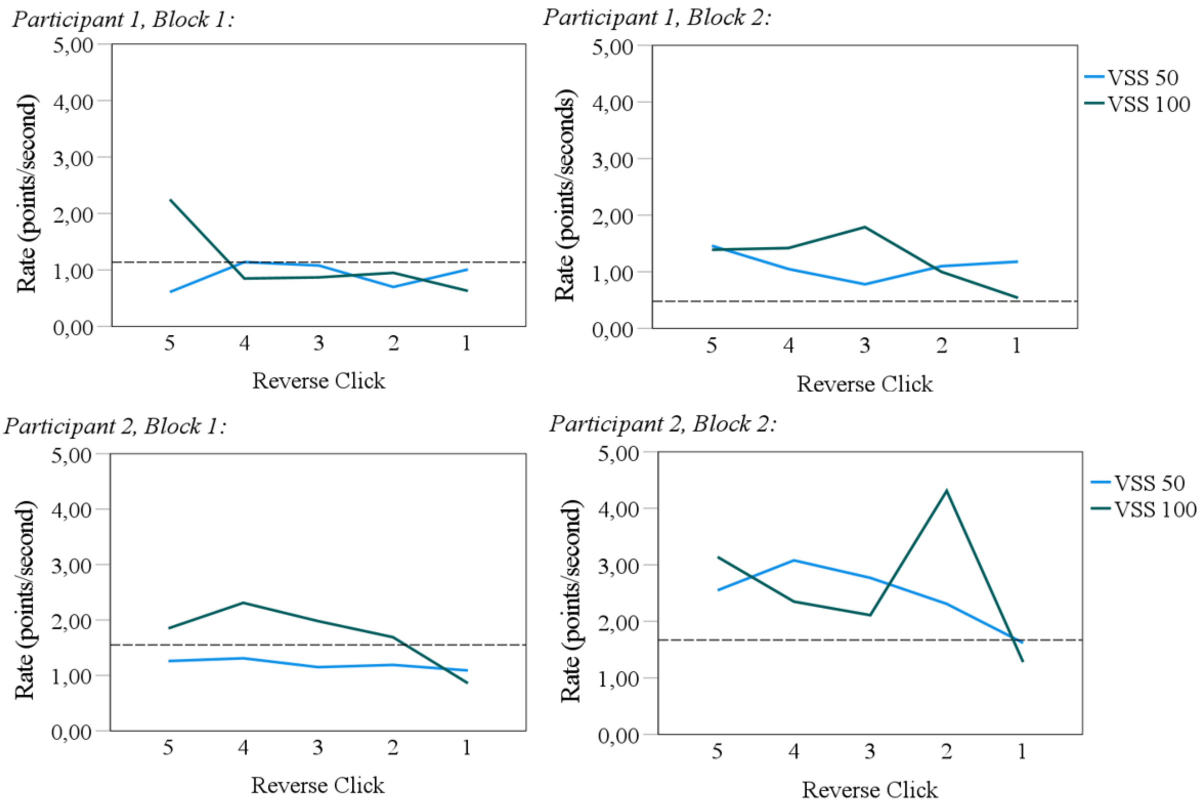


Figure 10. Rates of collection for each block for each participant. Participant 1 is at the top and Participant 2 is shown on the bottom, with the first block on the left and the second block on the right. The average rate of collection is represented by the dashed line. The instantaneous rate of collection is shown for the last five reverse clicks for both of the two visual set sizes (50, 100). An optimal forager's instantaneous rate of collection should only drop below the average rate at reverse click 1.

Semi-structured interview

In the subsequent interview about their experience of performing the hybrid foraging task, both participants spontaneously mentioned that they suspected they had forgotten some target objects and had consequently not selected these target objects throughout the whole task. Both participants also reported that the task seemed to get easier in the second block, after they had figured out what the task entailed.

When asked, neither participant mentioned having a specific strategy, but Participant 1 described how after finding the first target in a new patch, the rest of the target objects seemed easier to locate. When asked if they consciously searched each patch exhaustively, the participants differed in their own accounts of their search strategies. Participant 1 reported specifically trying to find all targets in a patch before moving to the next patch, while Participant 2 reported being very aware that they were not finding all targets in each patch before moving on but seeing this as a tradeoff for speed. Both participants reported that the screen size, object size and speed of object movement was appropriate. Additionally, both participants spontaneously referred to the hybrid foraging task as a "game" and called the task "fun".

Discussion

Because only two participants were included in this experiment, all analyses are tentative and not necessarily representative of the entire target groups of people over 65 years. However, patterns have been indicated in this experiment that may be relevant to consider in future testing. For instance, for both the spatial placement of false alarms and the spatial placement of validly collected target objects, there appears to be a tendency to collect objects that are near the center of the screen.

Additionally, when looking at the spatial placement of collected target objects, there seems to be a tendency for both participants to collect target objects in the bottom right corner less often than the remaining three corners. Since approximately 90% of the population are believed to be right-handed (Papadatou-Pastou et al., 2020), it is statistically likely that both participants tested here were right-handed. If both participants were right-handed, it is hypothesized that this spatial bias in target collection may be caused by their right hand covering the lower right corner of the screen when they are collecting target, making it so that they can't see potential targets in this section of the screen, and therefore collect targets in the bottom right corner less often.

Wiegand and Wolfe (2021) found that the number of patches viewed in a block and the proportion of targets left behind in each patch varies between participants. This finding is also reflected in the results of this experiment, with the number of patches viewed ranging from 25 to 46, and the average number of target objects left behind in a patch ranging from 5,48 to 10 objects.

Based on previous research, it was expected that the two participants over 65 years would forage each patch exhaustively and thus not forage optimally according to MVT (Wiegand et al., 2019; Wiegand & Wolfe, 2021). In the first block of the task, neither participant forages optimally, as illustrated by Table 1 and the graphs in Figure 10. However, both participants appear to forage more optimally in the second block of the task, with Participant 1's instantaneous rate of collection never going under the average rate, while Participant 2's instantaneous rate of collection only drops below the average rate at the very last click in each patch. Based on this, the two participants in this experiment differ from the participants in this age group previously tested using the hybrid foraging task. Perhaps these two participants are simply unrepresentative of the target group, or perhaps it is a result of these two participants being Danish in nationality, while the previously tested participants were recruited in Massachusetts, USA (Wiegand et al., 2019; Wiegand & Wolfe, 2021). This is not possible to determine from this the results of this experiment but will be investigated further in the third experiment described in this project.

The difference seen between the participants' performance on the two blocks is also reflected in the subsequently done interview, where both participants reported that searching for the target objects was easier in the second block. These statements, alongside the differing optimal foraging results in the two blocks, introduces the possibility that the first block may be more appropriately considered as a practice trial, and should therefore not be taken into account when analyzing the data from the hybrid foraging task. At the very least, if this theory is found to be correct, then this needs to be taken into account if this hybrid foraging task is to be used as an assessment method in a clinical setting.

The travel time between the patches used in this study varied between the two blocks, with a travel time of one second in the first block and three seconds in the second block. Given the previously mentioned differences in foraging behavior between the two blocks, this variance in travel time may be an unintended confounding variable.

Experiment 2

Based on the results of the first experiment, a second experiment was conducted. The main goal of the second experiment was to examine if the difference between the first and second block would level out after more blocks, or if the performance on the block would keep changing. This was done in order to determine if the first two blocks are indeed representative of the foraging behavior seen in the following blocks, or if the first block should only be seen as a training block, and not included in the analysis of the data. This was examined by adding more blocks to the experiment. Furthermore, the travel time between patches will be homogenized in this study, in order to eliminate the possibility that this could be a confounding variable when comparing the two blocks of the task.

Participants

The two participants who took part in the first experiment were re-recruited and asked to perform the hybrid foraging task again, in order to ascertain if the difference between the performance on the two blocks would plateau. Both participants agreed to take part in the second experiment. As in the first experiment, participation in the second experiment was voluntary and did not entail monetary compensation.

Stimuli and apparatus

The stimuli used to assess hybrid foraging search in the first experiment was also used in this study. The task was performed on the same tablet as described in the first experiment.

In this second experiment, the previously done semi-structured interview was condensed into a short paper-and-pencil questionnaire. In this questionnaire the participants were asked about their age, gender, nationality, and their level of education. The participants were also asked to explain the hybrid foraging task that they had just completed in their own words and asked if they had any strategies when completing this task. As a control, the participants were also asked about their ability to use a touchscreen and how often they use touchscreens in their everyday life. Additionally, the questionnaire also asked about the participants' handedness, as this may explain some of the spatial patterns seen in the first experiment. The questionnaire consists of a mixture of demographic questions, multiple choice questions and open-ended questions, where the participant is asked to write in their answer. See Appendix B for a copy of the questionnaire used.

Procedure

The procedure used in the second experiment is identical to the procedure used in the first, with the following exceptions. Firstly, the hybrid foraging task was performed by each participant three times. The participants were presented with eight target objects and their recognition of these objects were tested using the recognition test described in Experiment 1.

Afterwards the participants performed the hybrid foraging task for two blocks, each with a goal of 500 points. When the two blocks had been completed, the participants started over with a presentation of eight new target objects and the subsequent recognition test and hybrid foraging search task. The hybrid foraging task was performed three times in total for each participant, meaning that each participant performed six blocks of hybrid foraging, in addition to the two blocks performed in the first experiment. All eight blocks from the first and second experiment were included in the analysis of the data. Secondly, the second experiment also deviated by adding specific instructions stating that it can be checked if a given object is a target object by clicking on the object. If the object turns red, then it is not a target object. If the object disappears, then it is a target object. This instruction was added because both participants in the first experiment stated that they felt they had forgotten their target objects and were sometimes unsure if an object was a target or a distractor. Lastly, the travel time between patches was made uniform, so that there was a 2000 ms travel time between patches in both the first and the second block.

After the participants had performed the hybrid foraging task three times, they were asked to fill out the revised questionnaire. They were given the questionnaire in a printed form and asked to fill it out using a pen.

Results

The data analyzed in this section consists of the data collected in the second experiment, along with the data collected in the first experiment. The two blocks completed in the first experiment will be referred to as block one and two, while the six blocks completed in the second experiment will be referred to as block three, four, five, six, seven and eight.

Descriptive

As in the first experiment, the first and last patch of each block were excluded from the analysis. The number of valid patches for each block was reported in Table 2. Across all eight blocks, Participant 1 went through an average of 23,88 valid patches while Participant 2 saw 10,88 valid patches per block. Additionally, the average number of uncollected targets in a patch was calculated for each of the eight blocks and is presented in Table 2. When averaged across all eight completed blocks, Participant 1 left an average of 8,42 target objects behind when leaving a patch, while Participant 2 left an average of 3,92 uncollected target objects behind.

Valid patches and uncollected targets for each block:

	Participant 1		Participant 2	
Block	Valid patches	Average uncollected targets	Valid patches	Average uncollected targets
1	28	11,68	11	4,91
2	18	7,39	14	5,93
3	34	13,41	10	3,70
4	31	11,25	13	5,69
5	22	8,23	10	3,50
6	19	6,00	12	5,25
7	23	3,74	9	2,11
8	16	4,63	11	2,27

Table 2. The number of valid patches and average number of uncollected targets for each participant. The average number of uncollected targets indicates the average amount of targets left behind in a patch when traveling to the next patch. Both measures are reported for each of the eight blocks performed by the participants.

Participant 1:

M = 14,5 Min = 1 Max = 24	*M* = 17,25 Min = 5 Max = 24	*M* = 15 Min = 8 Max = 21	*M* = 6 Min = 1 Max = 11
M = 24 Min = 5 Max = 34	*M* = 17 Min = 6 Max = 25	*M* = 20,9 Min = 11 Max = 29	*M* = 11,75 Min = 2 Max = 20
M = 31,75 Min = 7 Max = 26	*M* = 24,75 Min = 5 Max = 38	*M* = 24 Min = 4 Max = 42	*M* = 18,75 Min = 4 Max = 27
M = 15 Min = 1 Max = 26	*M* = 17 Min = 5 Max = 27	*M* = 13,5 Min = 3 Max = 18	*M* = 7,75 Min = 2 Max = 11

Participant 2:

M = 0,25 Min = 0 Max = 1	*M* = 1,25 Min = 0 Max = 4	*M* = 1,75 Min = 0 Max = 4	*M* = 0 Min = 0 Max = 0
M = 0,5 Min = 0 Max = 1	*M* = 5 Min = 2 Max = 7	*M* = 0,5 Min = 0 Max = 2	*M* = 0 Min = 0 Max = 0
M = 3,25 Min = 1 Max = 6	*M* = 6,75 Min = 3 Max = 12	*M* = 2 Min = 1 Max = 3	*M* = 0,5 Min = 0 Max =1
M = 0,75 Min = 0 Max = 2	*M* = 1,5 Min = 0 Max = 4	*M* = 1,5 Min = 0 Max = 3	*M* = 0 Min = 0 Max = 0

Figure 11. Frequency of false alarms per section for Participant 1 (top) and Participant 2 (bottom). The total amount of wrongly clicked distractor objects in each section for each of the eight blocks is averaged and written in the corresponding section of the table. The lowest number of false alarms as well as the highest number of false alarms for each section is also reported.

The number of false alarms for each section was calculated and reported in Figure 11. The average number of false alarms throughout the eight blocks for each participant is reported for each section, as well as the lowest and highest number of false alarms in a block for each section. Additionally, the false alarm rate for each participant across all eight blocks was calculated. For Participant 1, the false alarm rate was 0,29 and for Participant 2 the false alarm rate was 0,05. Because this data is reported for the task as a whole and therefore not for each block, each participant only has data from four trials. For that reason, the standard deviation will not be calculated for this experiment. Additionally, the data will only be reported descriptively for this reason, and not analyzed further. From this point, the false alarms were excluded from the dataset, so that moving forward, only the valid clicks were analyzed.

Participant 1:

M = 3,68 Min = 2,8 Max =4,4	M = 6,33 Min = 5,8 Max = 7,2	M = 5,55 Min = 4,1 Max = 7,4	M = 1,4 Min = 0,6 Max = 3
M = 9 Min = 7,2 Max = 10,6	M = 10,68 Min = 8,8 Max = 11,8	M = 8,68 Min = 7,3 Max = 9,6	M = 3,08 Min = 2 Max = 4,5
M = 8,55 Min = 7,6 Max = 10,2	M = 12 Min = 8,5 Max = 14,6	M = 11,23 Min = 8,8 Max = 13,8	M = 4,08 Min = 3,4 Max = 5,5
M = 3,03 Min = 1,4 Max = 4,6	M = 4,7 Min = 4 Max = 5,4	M = 5,55 Min = 4,3 Max = 7	M = 1,78 Min = 0,6 Max = 2,7

Participant 2:

M = 1,35 Min = 0,9 Max = 2,1	M = 3,88 Min = 2,2 Max = 4,9	M = 3,75 Min = 1,9 Max = 5,1	M = 1,38 Min = 1,1 Max = 1,6
M = 5,78 Min = 3,9 Max = 7,3	M = 14,33 Min = 13,5 Max = 15,4	M = 12,75 Min = 11,7 Max = 14,2	M = 3,83 Min = 3,1 Max = 4,3
M = 5,18 Min = 4 Max = 5,7	M = 14,85 Min = 11,4 Max = 18,1	M = 13,55 Min = 12,5 Max = 15,7	M = 4,9 Min = 4,3 Max = 5,7
M = 2,48 Min = 2 Max = 3	M = 6,03 Min = 3 Max = 7,7	M = 4,88 Min = 4,3 Max = 5,3	M = 1,13 Min = 0,6 Max = 1,6

Figure 12. Percentage of valid clicks done in each section for Participant 1 (top) and Participant 2 (bottom). The percentage of the total amount of valid clicks done in each section for each of the eight blocks is averaged and written in the corresponding section of the table. The lowest percentage of valid clicks as well as the highest percentage of valid clicks for each section is also reported.

Participant 1:

M = 1659,93 Min = 816,05 Max = 2879,42	*M* = 1629,51 Min = 1154,44 Max = 2398,83	*M* = 1300,28 Min = 739,23 Max = 2247,89	*M* = 1722,29 Min = 1497,35 Max = 2158,27
M = 1345,96 Min = 1089,33 Max = 1988,62	*M* = 1400,65 Min = 1040,74 Max = 2194,74	*M* = 1405,05 Min = 1160,33 Max = 1829,35	*M* = 1530,93 Min = 1018,19 Max = 2134,27
M = 1548,38 Min = 1289,12 Max = 1777,37	*M* = 1251,04 Min = 818,91 Max = 1633,15	*M* = 1304,71 Min = 1050,03 Max = 1832,42	*M* = 1353,22 Min = 982,41 Max = 1997,51
M = 1459,47 Min = 1215,92 Max = 1769,42	*M* = 1462,46 Min = 1066,5 Max = 2324,48	*M* = 1097,37 Min = 776,03 Max = 1478,74	*M* = 1373,68 Min = 1175,07 Max = 1786,94

Participant 2:

M = 744,87 Min = 422,00 Max = 1169,97	*M* = 865,80 Min = 626,96 Max = 1068,97	*M* = 814,69 Min = 717,35 Max = 958,99	*M* = 1023,00 Min = 701,06 Max = 1428,21
M = 952,77 Min = 833,89 Max = 1268,42	*M* = 1064,47 Min = 938,35 Max = 1186,88	*M* = 949,82 Min = 810,35 Max = 1109,22	*M* = 930,55 Min = 781,43 Max = 1115,76
M = 945,43 Min = 748,11 Max = 1193,64	*M* = 982,44 Min = 920,50 Max = 1038,00	*M* = 882,25 Min = 863,82 Max = 905,01	*M* = 751,56 Min = 645,06 Max = 872,59
M = 903,52 Min = 605,59 Max = 1089,13	*M* = 748,76 Min = 623,89 Max = 948,43	*M* = 818,67 Min = 726,39 Max = 923,92	*M* = 1049,62 Min = 869,47 Max = 1229,18

Figure 13. Reaction time per valid click for each section for Participant 1 (top) and Participant 2 (bottom). The reaction time for all valid clicks done in each section for each of the eight blocks is averaged and written in the corresponding section of the table. The time per click as well as the highest time per click for each section is also reported.

The percentage of valid clicks for each section is reported in Figure 12. Again, no further analysis will be performed on the data because of the small sample size. However, when looking at the descriptive data of the distribution of valid clicks around the screen, there appears to be more valid clicks performed in the center of the screen than around the edges. Specifically, it appears that the least amount of valid clicks are performed in the four corners of the screen.

The average reaction time for each valid click done in each section of the screen was also calculated and is presented in Figure 13. When examining the data visually, there does not appear to be any patterns in the reaction time for each click across the different sections of the screen. Participants were timed on their performance of the task in its entirety and across the four times the task was run for each participant, it took an average of 17,5 minutes for the whole task. This was used as an indicator for the time frame in future recruitment of participants.

Optimal foraging behavior

Based on the difference in optimal foraging behavior seen for both participants between the two blocks in the first experiment, this second experiment was conducted. More blocks were added, giving each participant a total of eight blocks. The optimal foraging of each participant was calculated using MVT, as described in Experiment 1. The results are reported in Table 3.

Rates of collection for Participant 1:

		VSS50					VSS100				
	AR	IR1	IR2	IR3	IR4	IR5	IR1	IR2	IR3	IR4	IR5
Block 1	1,14	1,01	0,70	1,08	1,14	0,61	0,63	0,95	0,87	0,85	2,25
Block 2	0,48	1,18	1,10	0,78	1,05	1,46	0,54	1,00	1,79	1,42	1,39
Block 3	0,65	1,33	1,27	1,66	1,58	1,60	1,52	1,82	2,60	1,52	1,81
Block 4	0,65	1,41	1,35	1,48	0,91	1,25	1,34	3,03	0,92	1,72	2,54
Block 5	0,70	2,35	2,23	5,13	2,01	3,00	1,89	2,24	2,24	2,68	1,85
Block 6	0,85	1,35	1,38	0,87	1,04	2,34	1,51	1,73	2,17	1,33	1,60
Block 7	0,63	1,16	2,19	1,66	1,98	1,87	1,36	0,85	1,16	1,72	1,44
Block 8	0,66	1,31	1,77	2,84	1,05	1,35	1,94	0,61	3,68	1,32	1,90

Rates of collection for Participant 2:

		VSS 50					VSS 100				
	AR	IR1	IR2	IR3	IR4	IR5	IR1	IR2	IR3	IR4	IR5
Block 1	1,55	1,09	1,19	1,15	1,31	1,26	0,86	1,69	1,98	2,31	1,85
Block 2	1,67	1,62	2,31	2,77	3,08	2,55	1,28	4,31	2,11	2,35	3,14
Block 3	1,76	1,34	1,49	1,17	1,69	2,38	1,37	2,27	2,14	2,31	3,62
Block 4	1,56	3,12	1,90	3,91	3,00	2,79	4,52	4,18	1,31	1,39	3,06
Block 5	1,82	1,41	2,47	2,14	2,24	4,64	1,87	1,67	2,17	1,51	2,22
Block 6	1,52	1,71	1,29	5,04	3,82	1,97	3,65	1,16	2,80	3,73	2,45
Block 7	1,69	2,95	4,39	2,01	1,79	4,64	3,18	1,98	2,49	2,46	1,97
Block 8	1,65	1,76	1,57	1,96	2,52	2,29	1,40	2,14	2,74	4,46	4,00

Table 3. Average rate of collection and instantaneous rate of collection. All calculations are shown for Participant 1 (top) and Participant 2 (bottom) separately. Both the average rate of collection (AR) and the instantaneous rate of collection (IR) is calculated for each block separately. The instantaneous rate of collection is calculated for the last five reverse clicks for each of the two visual set sizes (VVS). The AR is highlighted with green, while the instances where the foraging is nonoptimal and the instantaneous rate goes below the average rate are highlighted with red.

Handedness

In the questionnaire, both participants were asked about their handedness, among other things. This was done in order to control for the possibility that handedness could cause the participants to select target objects left often in the bottom corner of their dominant side, as their hand would likely block this area of the screen. Both participants reported being right-handed. When comparing this to the percentage of valid clicks in each section (Figure 12), it is clear that target objects are generally picked less often in the corners, but it appears that this pattern is especially true for the two corners on the right side of the screen. This indicates an effect of handedness on where on the screen target objects are picked, that would be relevant to investigate further in the third experiment.

Discussion

When looking at the number of valid patches and the average number of uncollected targets in a valid patch for each participant for each of the eight blocks, no clear pattern appears.

There is a marked difference between the two participants, but for each participant it doesn't seem to change much after the first two blocks. In the last two blocks performed, both participants appear to search more exhaustively than previously. This may possibly be an indicator of fatigue, as the participants had been performing the hybrid foraging task for approximately 35 minutes at the beginning of block 7. Overall, the first two blocks seem to be representative for the amount of valid patches and the average number of uncollected targets in the subsequent blocks.

The main reason for this second experiment was to examine if the foraging behavior would continue to change as much as it changed between the first and second block for both participants. When looking at the foraging behavior for all eight blocks included in this second experiment, the performance does seem to plateau after the first block. This is especially clear for Participant 1. For Participant 1, there is a big difference between the first and second block, but all following blocks closely resemble the behavior seen in the second block. For Participant 2 the pattern of the foraging behavior is less clear. For this participant, the subsequent blocks seem to be a mixture of the pattern seen in the first and second block. These results give an unclear picture of whether the first block should be understood mostly as a learning block.

The performance of the two participants is still very different from each other in the second experiment. This difference could be a result of normally appearing individual differences in foraging behavior, but it is also possible that an underlying factor could be the participants' cognitive resources and their chosen lifestyle. One aspect in which the participants especially differ from each other is in the number of false alarms throughout the entire task, where Participant 1 has notably more false alarms than Participant 2. In the general discussion of this paper, the false alarm rates from this experiment will be compared to the rates found in the larger sample in the third experiment, in order to determine their potential significance.

Experiment 3

A third experiment was carried out to investigate how the results of the hybrid foraging task are distributed over a larger group of people. Specifically, the main aims of the third experiment were to explore what spatial patterns of object collection can be expected within a normative sample, as well as to understand the optimal foraging behavior of a large sample of Danish adults over 65 years.

Because of the unclear pattern found between the blocks in Experiment 2, both blocks will be included in the calculations for the main study, but they will again be analyzed separately in order to further evaluate the role of each block. Additionally, a question asking the participants about their interests and hobbies was added to the questionnaire. This question was added as an indicative measure of the participants' cognitive resources and lifestyle, since this was hypothesized as an explanation for the difference between the two participants' foraging behavior seen in both Experiment 1 and 2. The underlying idea is that perhaps an active and mentally challenging lifestyle, as reflected by the person's hobbies and their level of education, keeps the older adults more mentally sharp (Stern, 2002) and leads to a better performance on the hybrid foraging task.

Participants

For the third experiment, participants were recruited from Facebook groups, Folkeuniversitet lectures, activity centers in Aalborg and by placing flyers in the local community. All participation in this experiment was voluntary. The inclusion criteria used for participation in this experiment was the same as in the preceding two experiments, where participants had to be 65 years old or older, have normal or corrected to normal visual acuity and have no known history of neurological disorders.

A total of 43 participants performed the hybrid foraging task and filled out the subsequent questionnaire. Three participants had to be excluded from the dataset because of technical issues when saving the data. This included a faulty internet connection obstructing the saving of one participant's data, and two participants whose data was saved incorrectly on the server. This left 40 participants who were included in the third experiment. Of the 40 participants, 35 (87,50%) were female, while 5 (12,50%) were male. Their ages ranged from 65 years to 86 years (*M* = 74,13 years, *SD* = 5,00 years). 38 participants reported being right-handed, while one participant reported being left-handed and one participant reported being ambidextrous. 39 of the participants reported their nationality as Danish, with the remaining participant reporting their nationality as American, but speaking fluent Danish. The 40 participants reported varying levels of education. Table 4 shows how many participants answered that a given education level was their highest.

Level of education	Number of participants
Primary and lower secondary education (Grundskole)	3 (7,50%)
Upper secondary education (Gymnasial uddannelse)	3 (7,50%)
Vocational education (Erhvervsuddannelse)	9 (22,50%)
Short-cycle higher education (Kort videregående uddannelse)	2 (5,00%)
Medium-cycle higher education (Mellemlang videregående uddannelse)	17 (42,50%)
Long-cycle higher education (Lang videregående uddannelse)	6 (15,00%)

Table 4. Table showing the number of participants who reported each level of education as their highest level. It is also reported what percentage of all participants in the study reported each level as their highest level of education. The levels of education were translated from Danish to English using the terminology used by Uddannelses- og Forskningsministeriet (n.d.) and the Danish terminology is written in parentheses.

Stimuli and apparatus

This experiment used the stimuli described in the previous experiments to assess hybrid foraging search. The hybrid foraging task was performed on the tablets described in previous experiments. The paper and pencil questionnaire described in Experiment 2 was also used in this experiment. As the only amendment to the questionnaire, a question was added to ask the participants about their interests and hobbies (see Appendix B).

Procedure

The third experiment largely followed the procedure described in Experiment 1. However, some modifications were made to the procedure described in the first experiment. Firstly, instructions were added to the hybrid foraging task telling participants that they can check if a given object is a target object or a distractor by clicking on the object and observing it the object disappears or turns red. Furthermore, the travel time between the patches was set to 2000 ms for both the first and the second block, as was also done in the second experiment. After performing the hybrid foraging task, participants were asked to fill out a pen and paper questionnaire.

Results

As in the previous experiments, the first and last patch in each block are invalid and are consequently excluded from further analysis. Additionally, one participant started the hybrid foraging task before being given the instructions to the task. In this case the two affected patches, during which the instructions were given, were invalid and excluded from the analysis.

This is an explorative experiment, where the aim is to understand how a control population of people over 65 years perform on the hybrid foraging task. Because of this, outliers in this sample will not be excluded from analysis, as the exclusion of outliers in exploratory research would artificially alter the sample mean (Kendall & Sheldrick, 2000).

Number of searched patches and time spent in patches

As in the previous experiments, the number of valid patches was calculated for each participant. The number of valid patches that each participant went through during the whole task varied between 16 and 41, with an average of 24,25 patches (*SD* = 5,28). A histogram of the number of valid patches for the whole task is presented in Figure 14. This histogram shows that the number of valid patches does not appear to be normally distributed in this sample. Furthermore, it illustrates that the majority of participants go through fewer than average valid patches, but that some participants search through notably more patches throughout the task, which may be skewing the average number of valid patches.

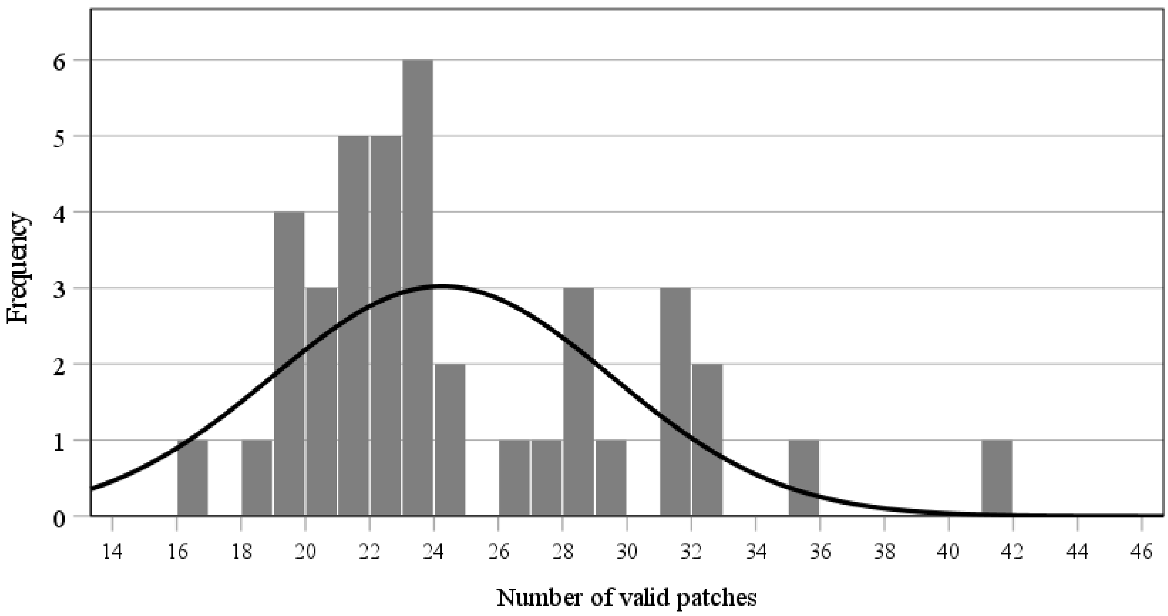


Figure 14. Histogram of number of valid patches. Each bar represents a given number of valid patches visited throughout the entire task and the height of the bar represents how many participants visited that specific number of valid patches.

$M = 2{,}25$ $SD = 0{,}90$	$M = 5{,}14$ $SD = 2{,}22$	$M = 4{,}86$ $SD = 1{,}18$	$M = 1{,}73$ $SD = 0{,}48$
$M = 5{,}61$ $SD = 1{,}29$	$M = 14{,}60$ $SD = 2{,}22$	$M = 12{,}76$ $SD = 2{,}71$	$M = 4{,}77$ $SD = 1{,}26$
$M = 5{,}65$ $SD = 1{,}20$	$M = 13{,}70$ $SD = 2{,}33$	$M = 11{,}71$ $SD = 2{,}09$	$M = 4{,}50$ $SD = 1{,}26$
$M = 2{,}06$ $SD = 0{,}74$	$M = 4{,}61$ $SD = 1{,}02$	$M = 4{,}28$ $SD = 1{,}42$	$M = 1{,}79$ $SD = 0{,}63$

Figure 15. A representation of the average percentage of valid clicks done in each of the 16 sections of the tablet screen. For each section, the mean percentage represents the fraction of all performed valid clicks that were done in that specific section. The standard deviation is also reported for each section.

The spatial placement of each valid click was also recorded. Because the amount of valid clicks varied between participants, the number of valid clicks in each section of the screen was calculated as a percentage of the total number of valid clicks, in order to make the placement of clicks comparable between participants. The percentage of clicks in each section was then averaged across all participants and the results of this are presented in Figure 15. A one-way ANOVA was performed in order to evaluate if the difference between the average percentage of valid clicks in each section was statistically significant. This found a statistically significant difference between the percentage of valid clicks in the different sections, $F(15, 624) = 334{,}09$, $p < 0{,}001$. By performing a post hoc Tukey HSD test, a pattern resembling the one presented in Figure 16 was found. The results of the Tukey HSD test can be seen in Appendix C. The average percentage of objects clicked in all four sections constituting the center of the screen was found to be significantly higher than the mean of the 12 sections constituting the edges of the screen.

Additionally, there were no significant differences between any of the four corner sections, but the mean percentage of valid clicks in all four corners was significantly lower than all other non-corner sections. The remaining sections in the middle of all edges of the screen (section 12, 13, 21, 24, 31, 34, 42 and 43 in Figure 6) were all significantly different from both the four center sections and the four corner sections. The results of the post hoc can be seen as an indication that the patterns of selection across the different sections, that can be seen in Figure 15, are indeed a statistically significant result.

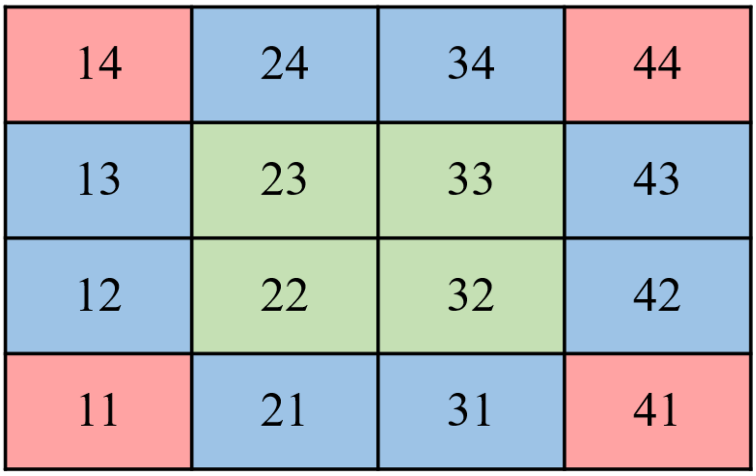


Figure 16. Illustration of the pattern found in the placement of valid clicks. The average percentage of valid clicks performed in all sections of one color are significantly different from all the sections in the two other colors. The green sections represent the four sections that make up the center of the screen. The mean percentage of valid objects collected in each of these four sections was found to be significantly higher than the mean of all other sections. The red sections represent the four corners of the screen and the mean percentage of valid clicks done here was significantly lower than the means of both the green and the blue sections. The blue sections represent the middle of all edges on the screen and the mean percentage of valid clicks in these sections were all significantly lower than the mean of the green sections but significantly higher than the mean of the red sections.

Although it would have been relevant to examine the effect of handedness on the percentage of valid clicks done in each section of the screen, only one participant reported being left-handed, while one other reported being ambidextrous, but using their right hand. Because of this, no attempts at analyzing the effect of handedness will be made in this experiment. However, the vast majority of participants in this study used their right hand to perform the task

(39 out of 40), so if there was an effect of handedness, it would likely be apparent. While the average percentage of valid clicks on the far-right side of the screen appear to be lower than the corresponding sections on the left side of the screen (as seen in Figure 15), the previously performed ANOVA does not indicate that this difference is statistically significant.

The average of total time spent searching the patches was similar across the two blocks, as is illustrated by Figure 17. The total time includes all the time spent in each patch calculated for each block and does not include travel time between the patches. The time spent in patches is measured in milliseconds but will be converted and presented in seconds for clarity. In block one, the average time spent in the patches was 390,57 seconds (*SD* = 157,25) and in block two the average time spent was 359,82 seconds (*SD* = 133,98). Figure 17 shows that while the mean of the time spent in patches in the first block is lower than the mean of time spent in the second block, this difference is by no means significant, as the large overlap in the boxplots for each block.

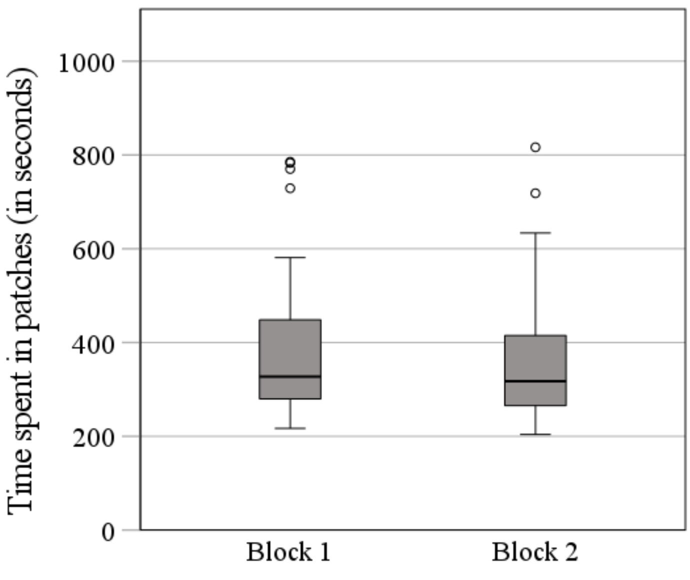


Figure 17. Box plot of summation of time spent in patches in each block. Each participant in experiment 3 is represented by one data point in block 1 and one data point in block 2. The boxplots show the mean time spent in patches for each block as the horizontal line within each box. The upper and lower quartiles are shown by the whiskers. Outliers for each block are marked by single data points but will not be excluded in the analysis.

False alarms and uncollected targets

How many false alarms each participant had varied from 0 to 60, with an average of 14,98 false alarms (*SD* = 14,22). The placement of these false alarms on the screen of the tablet was also recorded, and the average number of false alarms in each section is presented in Figure 18. The average false alarm rate was calculated across all participants to be 0,03 (*SD* = 0,03).

M = 0,20 *SD* = 0,46	*M* = 0,73 *SD* = 1,01	*M* = 0,75 *SD* = 1,21	*M* = 0,65 *SD* = 1,92
M = 0,70 *SD* = 1,20	*M* = 2,10 *SD* = 2,43	*M* = 2,18 *SD* = 2,35	*M* = 0,95 *SD* = 1,45
M = 0,73 *SD* = 1,11	*M* = 2,10 *SD* = 2,28	*M* = 2,00 *SD* = 1,88	*M* = 0,58 *SD* = 0,98
M = 0,33 *SD* = 0,62	*M* = 0,48 *SD* = 0,82	*M* = 0,63 *SD* = 1,21	*M* = 0,48 *SD* = 1,47

Figure 18. Descriptive statistics for the average number of false alarms in each of the 16 sections of the tablet screen. For each section, the mean number of false alarms is presented along with the standard deviation for the false alarms in that section.

It was also calculated how many target objects each participant left behind in a patch on average. This was calculated for each participant for both the first and second block of the task. The mean number of uncollected targets varied between participants, with some participants leaving an average of 0 target objects behind when moving to the next patch, while others left an average of 10,76 target objects uncollected. The number of uncollected target objects in each patch were averaged for all participants, finding that an average of 3,39 target objects (*SD* = 2,90) were left behind in the first block, while an average of 3,22 objects (*SD* = 2,83) were left behind in the second block.

Mean time per click across the different sections of the screen

Additionally, the mean time per click for each of the sixteen sections of the screen was also calculated, as is shown in Figure 19. The mean time per click is calculated for each section for each participant, and the averages of these times are presented here. In order to investigate if there was a significant difference in the average time per click for each section, a one-way

ANOVA was performed. No significant differences were found between the means of the sixteen sections, $F(15, 624) = 1{,}03$, $p = 0{,}42$. This means that the tendency to pick more objects in the center of the screen does not translate to picking objects significantly faster in the center than in the edges of the screen.

$M = 1519{,}23$ $SD = 692{,}70$	$M = 1411{,}06$ $SD = 522{,}44$	$M = 1481{,}79$ $SD = 485{,}62$	$M = 1554{,}77$ $SD = 636{,}74$
$M = 1350{,}21$ $SD = 492{,}79$	$M = 1288{,}48$ $SD = 360{,}43$	$M = 1340{,}42$ $SD = 390{,}84$	$M = 1424{,}16$ $SD = 472{,}07$
$M = 1299{,}24$ $SD = 536{,}19$	$M = 1295{,}18$ $SD = 411{,}10$	$M =1378{,}99$ $SD = 528{,}17$	$M = 1480{,}44$ $SD = 595{,}96$
$M = 1383{,}47$ $SD = 607{,}28$	$M = 1388{,}79$ $SD = 567{,}96$	$M = 1338{,}79$ $SD = 579{,}28$	$M = 1547{,}86$ $SD = 781{,}82$

Figure 19. A representation of the average time per click in each of the 16 sections of the tablet screen. The time per click is reported in milliseconds and for each section, the mean and the standard deviation is reported.

First and last picked objects in each patch

In order to investigate search patterns in the participants, the first and last objects picked in each valid patch were recorded and illustrated by Figure 20. In Figure 20, the location of the first and last object that was picked in every valid patch is illustrated by a datapoint, creating a visual illustration of where on the tablet screen the participants searched for the first target object. This figure shows that there appears to be a tendency to search for the first target object near the middle of the screen and just to the left of the “next” button. This figure also shows that participants appear to forage in a more dispersed manner across the majority of the tablet screen when searching for the last picked object in a patch.

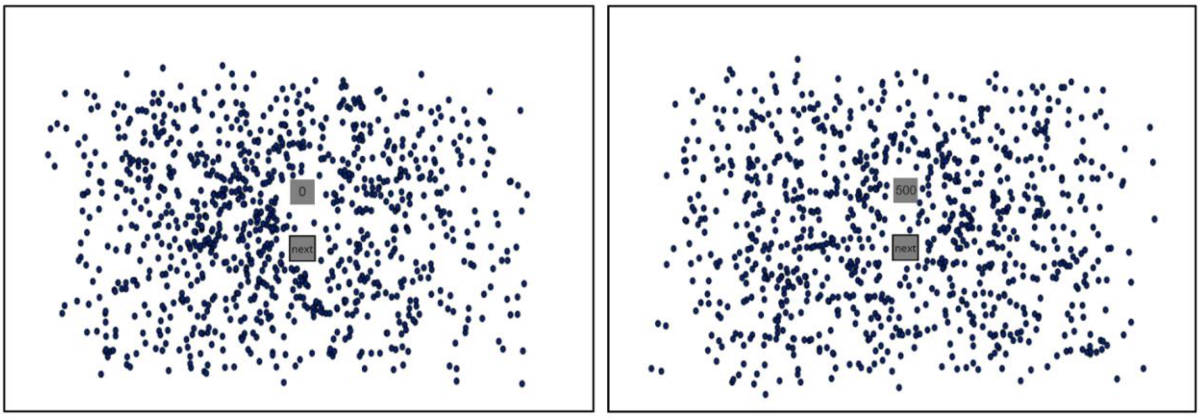


Figure 20. The placement of where the first (left) and last (right) object of each valid patch is picked. The first and last object picked in a patch was recorded for all participants and each datapoint on the left figure represents the location of the first object picked on the tablet screen, while each datapoint on the right figure represents the location of the last object picked on the tablet screen.

Target types

The number of times each target was picked was calculated in order to investigate how many of their eight target figures were collected by each participant throughout the hybrid foraging task. This showed that out of the 40 participants, 28 participants (70%) collected instances of all eight target objects throughout the entire task. However, nine participants (22,50%) collected seven different target types, while three participants (7,50%) collected only six of their eight target types. Furthermore, four other participants collected a large number of instances of one distractor object. The number of times these four participants erroneously collected the same distractor object ranged from 11 to 37 times.

Optimal foraging behavior

A measure of optimal foraging behavior was calculated using the MVT. The average rate of collection was calculated for each participant and the average and standard deviation of these calculations are reported in Table 5 for each block. The instantaneous rates of collection were also calculated for each participant. The instantaneous rate was calculated for the last five clicks of each patch (reverse click 1 through 5) and calculated separately for each block and each visual set size. The rates of all participants in the study were then averaged and the results of this are reported in Table 5. The relationship between the average rate and the instantaneous rate is what determines if a given foraging behavior is considered optimal. As shown in Table 5, the instantaneous rates of collection for each of the visual set sizes can be compared in each block. The instantaneous rates of collection are higher in the visual set size condition with 50 objects in six of the reverse clicks (Reverse click 1 and 3 in block one and reverse click 1, 2, 3 and 5 in block two), whereas they are higher in only four of the reverse clicks in the condition with the visual set size of 100 objects (Reverse click 2, 4 and 5 in block one and reverse click 4 in block two). The relationship found in this study between the average rate and the instantaneous rates is illustrated in Figure 21.

Comparisons of the rates of collections:

		VSS50					VSS100				
	AR	IR1	IR2	IR3	IR4	IR5	IR1	IR2	IR3	IR4	IR5
Block 1	1,17 (0,34)	1,08 (0,58)	1,32 (0,65)	1,58 (0,84)	1,62 (0,64)	1,62 (0,75)	1,05 (0,64)	1,35 (0,77)	1,52 (0,75)	1,69 (0,77)	1,68 (0,86)
Block 2	1,25 (0,33)	1,30 (0,66)	1,61 (0,76)	1,66 (0,75)	1,71 (0,70)	2,21 (0,52)	1,22 (0,61)	1,43 (0,73)	1,61 (0,81)	1,80 (0,86)	1,86 (0,96)

Table 5. The numbers in this table represent the mean of all participants in experiment three with the standard deviation written in parenthesis, The collection rates are calculated for each block. The average rate of collection (AR) represents the average number of points collected per second throughout all patches in the block. The instantaneous rate of collection (IR) is calculated for the last five reverse clicks of each patch and represents the average number of objects collected per second for that specific reverse click. The instantaneous rate of collection is calculated separately for each of the two visual set sizes (VSS50 and VSS100). Foraging behavior is not optimal if the instantaneous rate of collection falls below the average rate of collection for the whole block.

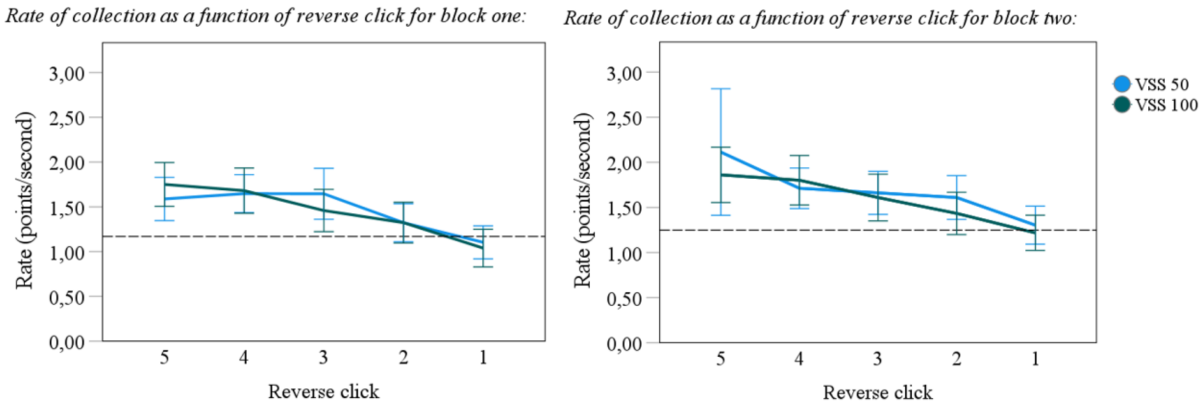


Figure 21. Line graphs showing the rate of collection as a function of the reverse click for block one (left) and block two (right). The instantaneous rates of collection (illustrated by the solid lines) were calculated for each block and are shown for the last 5 clicks in a patch. The solid line represents the mean of the instantaneous rates of collection across all participants, and the error bars represent a 95% confidence interval. The blue solid line represents the instantaneous rates of collection for the visual set size of 50 objects, whereas the green solid line represents the instantaneous rates of collection for the visual set size of 100 objects. The average rate of collection across all participants was calculated separately for each block and the mean average rate of each block is represented with a dashed line.

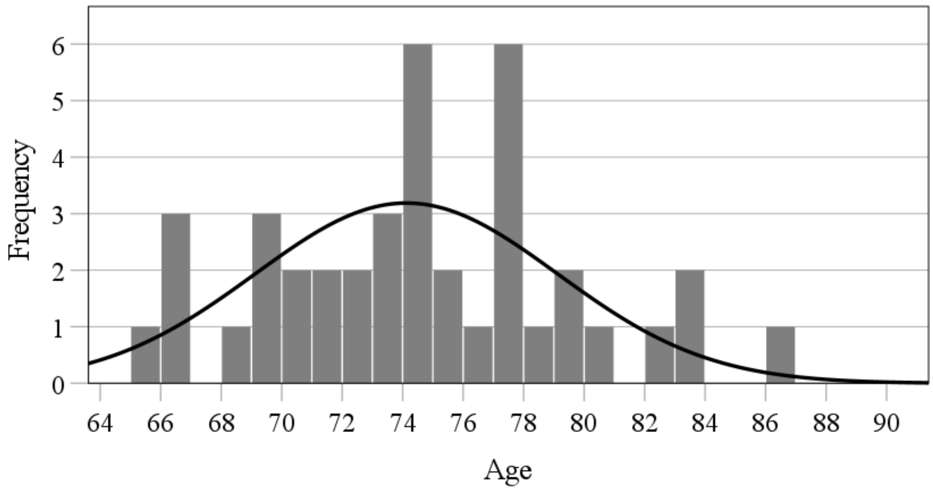
Demographic comparisons

The foraging behavior of participants was also assessed in relation to their demographic data, as reported in the questionnaire. The average rate of collection was used as an indicator of search efficiency, as this represents how many points were collected per second for each participant. Each participants' average rates of collection for block 1 and block 2 were averaged. This was done to give an overall measure of search efficiency throughout the entire task for each participant.

First, the average rate of collection for both blocks was compared to the participants' age. Because both the age and the average rate are scale measurements, it was necessary to investigate if the data in both variables were normally distributed. By looking at a histogram of the data (Figure 22), it was not possible to determine if the average rate or the age was normally distributed. Because of the small sample size, a Shapiro-Wilk test was performed on both variables, which did not show evidence that the average rate was non-normal (W = 0,97, p =

0,25). Additionally, no evidence was found that the age variable is not normally distributed (W = 0,98, p = 0,66). Based on this, a two-tailed Pearson's correlation was calculated, which found that age and average rate of collection are moderately and negatively correlated, $r(38) = -0,59$, $p < 0,001$. The correlation between average rate of collection and age is illustrated using a scatter plot in Figure 23.

Histogram of Age



Histogram of Average Rate

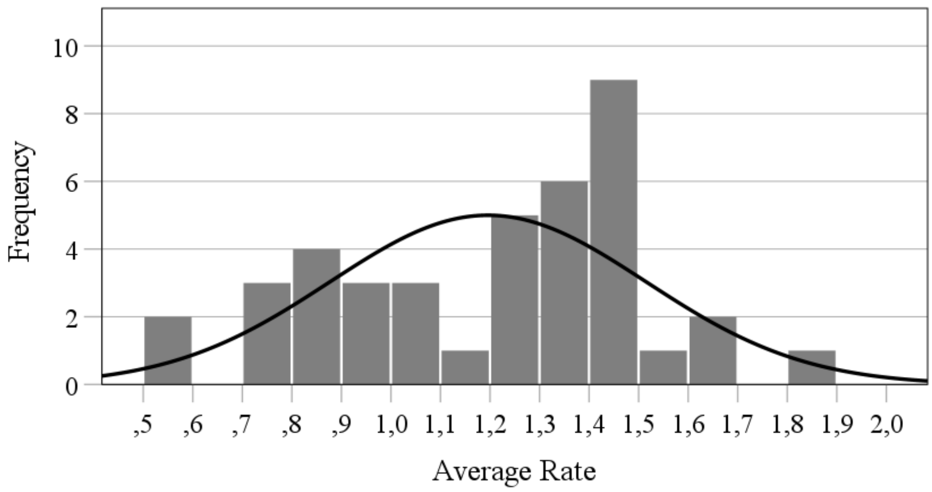


Figure 22. Histograms of age (top) and average rate of collection (bottom). A normal distribution curve is shown for each graph. For the histogram of age, the frequency of how many times each age was reported is shown by the height of the bars in the age graph. For the histogram of average rate, the average rate was binned in intervals of 0,1 and each average rate is placed in one of these intervals. The number of average rates in each interval is shown by the height of the bars.

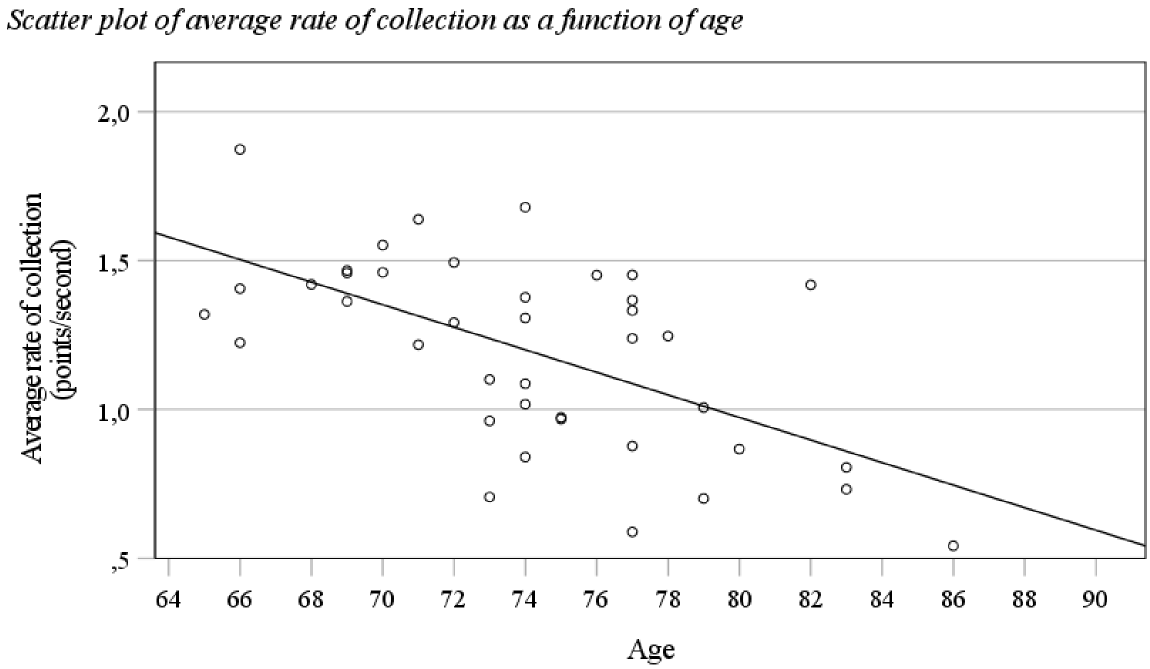


Figure 23. Scatter plot illustrating the correlation between average rate of collection and age. The average rate of collection across the whole hybrid foraging task is calculated for each participant, and one data point in the scatter plot represents each participant in this experiment. The moderate and negative correlation between the average rate of collection and age is illustrated by the solid line.

Furthermore, the relationship between the average rate of collection and the level of education was also relevant to examine. Because the level of education is an ordinal measure, a Spearman's rank correlation was computed between level of education and the average rate of collection. No significant correlation was found between the two variables ($r(38) = 0{,}04$, $p = 0{,}82$).

It is also relevant to examine the effect on lifestyle, as measured by the participants' self-reported hobbies on the questionnaire, on foraging efficiency. The self-reported hobbies mentioned by each participant were counted, and the number of hobbies reported was used as a measure of the activeness of a participant's lifestyle. This is by no means a perfect measure, and the results of this should therefore be interpreted with that in mind. The number of hobbies reported by each participant can be seen in the histogram in Figure 24.

Histogram of number of hobbies mentioned

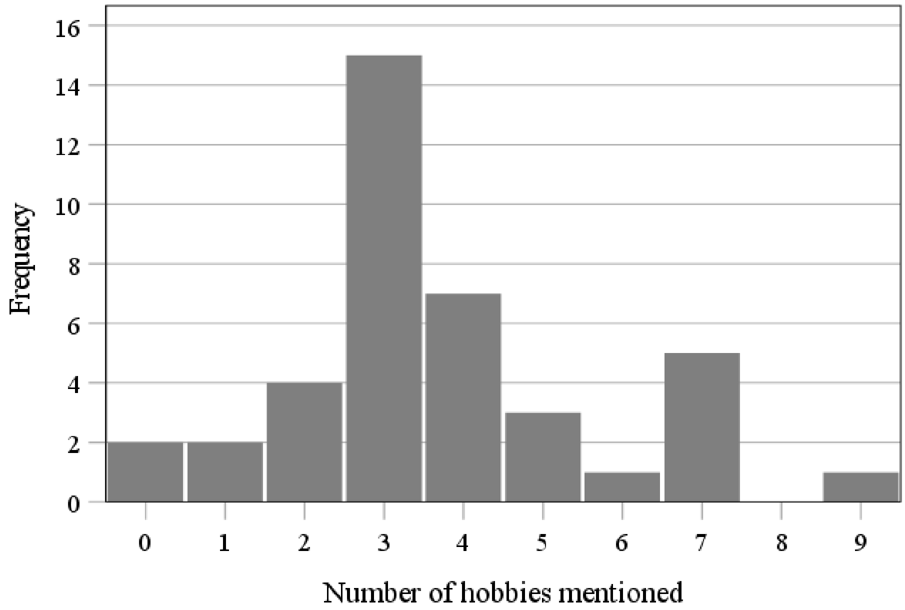


Figure 24. Histogram showing how many participants who reported each number of hobbies.

The 40 participants in this experiment were then divided into two equal groups, based on the median number of hobbies reported (median = 3). The 50% of participants with the highest number of reported hobbies were placed in the “high hobby” group, while the 50% of participants with the lowest number of reported hobbies were placed in the “low hobby” group. The low hobby group was made up of 20 participants (80% female) and had an average age of 75,1 years (*SD* = 4,55 years). There were also 20 participants in the high hobby group (95% female), and the group had an average age of 73,15 years (*SD* = 5,35 years). To compare the foraging efficiency across the high hobby group and the low hobby group a two-tailed independent sample t-test was performed, which found that the mean average rate of the low hobby group (*M* = 1,14, *SD* = 0,32) was not significantly different from the mean average rate of the high hobby group (*M* = 1,26, *SD* = 0,31), *t*(38) = -1,22, *p* = 0,23. This indicates that there was no difference between the efficiency of search for participants who reported having many hobbies and participants who reported having few hobbies.

Discussion

The three experiments performed in this study were designed to test if the hybrid foraging task could be used in a bedside test format, with the goal of potentially being a tool for visuospatial neglect assessment. This section will summarize and discuss the implications and relevance of some of the patterns seen in the performance on the hybrid foraging task throughout the three experiments done in this study. Since this study has taken an explorative approach, there are many different measures from the hybrid foraging task that are relevant to examine. Because of this, the general findings of the three experiments will be presented and discussed in categories. The patterns found in this study will be compared to prior research and the results from comparable previous studies.

Are the two blocks different?

A question was raised after the first experiment regarding the comparability of the two blocks used in this hybrid foraging task. Based on seemingly different optimal foraging measures in the first and second block, as well as the participants' own statement that the second block of the hybrid foraging task was easier, it was relevant to examine if this difference between blocks was a result of block one taking the place of a learning trial. When each participant was asked to perform several more blocks of the hybrid foraging task in experiment two, the pattern created by the measure of optimal foraging in each block (as seen in Table 3) remained somewhat unclear. For this reason, it was necessary to continue the examination of potential differences between the two blocks into the third experiment. When testing a larger sample of participants, no significant differences were found between the optimal foraging measures of block one and block two. Although both the average rate of collection and the instantaneous rates of collection were consistently lower in the first block, the standard deviations of all measures in block one overlap with the standard deviations of the corresponding measures in block two.

When looking at the average of total time spent in patches for each of the two blocks, no significant difference was found. Additionally, the number of uncollected targets was very similar for the two blocks. These two measures indicate that the patch leaving strategy and exhaustiveness of search was comparable across the two blocks.

Overall, these results indicate that the difference between the first and the second block, as seen in the first experiment, is not statistically significant when testing a larger sample of participants. This was relevant to examine in order to determine if changes, such as an added learning block, should be made to the hybrid foraging task in the future to optimize the validity of the measurements. Given the results from Experiment 3, this does not appear to be a necessary amendment to the hybrid foraging task in the future.

Valid patches searched

The results of all three experiments performed in this study indicate that there is a significant naturally occurring pattern in where on the screen target objects are collected. This is especially apparent in the significant results of the analysis done on the spatial placement of valid clicks in Experiment 3. These results indicate a pattern like the one presented in Figure 16. This pattern is relevant to highlight because the hybrid foraging task is being proposed as a tool for assessment of visuospatial neglect. In order to examine patients with visuospatial neglect for abnormalities in their pattern of object collection, it is necessary to first be aware of the naturally occurring patterns of object collection on the hybrid foraging task. The pattern indicates that if a patient, who is suspected of having visuospatial neglect, performs the hybrid foraging task and does not collect any objects near the very edge of the screen on either the left- or right-hand side, this is not a direct indicator of visuospatial neglect, seeing as very few objects are picked there in this sample of healthy older adults with no neurological disorders or injuries.

However, it is also relevant to note that this pattern does not indicate that healthy older adults do not attend to the corners and edges of the screen. Most likely, the percentage of valid clicks performed in each section is a reflection of where the objects are shown on the screen. It is not possible to report where on the screen all objects are located, only the location of each collected object. But from screenshots of the task (see Figure 4) it is clear that the objects are not always evenly distributed across the screen. This is important to be aware of, because it gives us reason the take the previously mentioned pattern with a grain of salt, as it may simply be a result of the underlying structure of the task, rather than participants truly not picking objects near the edges of the screen as often as in the center.

The results of the first experiment indicated that the handedness of the participants may influence where on the screen target objects were collected, with fewer objects collected in the bottom right corner than in any other section of the screen. In experiment two, it was confirmed that the two participants were indeed right-handed. In the second experiment, the handedness hypothesis was somewhat weakened, with participants finding less target objects in the corners in general, yet still appearing to find less items in the corners on the right-hand side in general. It was not possible to analyze the effect of handedness on the placement of valid clicks performed in the third experiment, due to only one participant performing the task using their left hand. However, the results of the general spatial distribution of valid clicks indicate that the results first attributed to handedness, may instead be a result of the general tendency to select fewer objects in the corner sections of the screen.

Mean time per click across the different sections of the screen

It was also relevant to determine if neurologically healthy participants had differences in reaction times when collecting targets across the different sections of the screen. This was examined in order to be able to evaluate if patients with visuospatial neglect have slower reaction times than can be expected in their neglected areas. For this reason, the mean time per click in each of the sections of the screen was calculated in all three experiments of this study. In Experiment 1, the mean time per click in each of the sixteen sections of the screen was visually evaluated. Based on this visual evaluation, it appeared that there was a pattern to the mean time per click across the screen for one of the participants, but not for the other. The data from Experiment 2 was visually evaluated as well, and no apparent pattern in mean time per click for the different sections was found. Likewise, no difference in mean time per click between the sixteen sections of the screen was found when the data from the larger sample was analyzed in experiment three.

However, it is relevant to note that because objects moved around the screen at random, this means participants sometimes experienced that the objects overlapped. In the cases where two target objects overlapped, the participants were able to collect the second of the two target objects almost instantaneously. This is necessary to be aware of as it may be contributing to an artificial lowering of mean time per click. In future research, it would be relevant to investigate further if this affects all sections of the screen equally, or if this is a factor that needs to be accounted for moving forward.

Demographic information

It was also relevant to determine if factors such as age or level of education had an effect on performance on the hybrid foraging task. This was examined in the third experiment, where it was investigated if there were any patterns in optimal foraging behavior on the basis of the demographic information reported by the participants in the questionnaire. No difference in foraging behavior was found for participants with different levels of education. Furthermore, no differences in foraging behavior was found between participants with many reported hobbies and few reported hobbies. Since both hobbies and level of education can be understood as measures of a cognitively stimulating environment (Stern, 2002), this is interpreted as indication that having a cognitively stimulating environment does not affect foraging behavior on the hybrid foraging task.

When comparing the participants' hybrid foraging behavior with their respective age, a significant, moderate, and negative correlation was found. This indicates that as people get older, they will begin to collect less points per second. In other words, search gets slower and less efficient with age. This finding is consistent with research previously done on the subject, where a general slowing of reaction time on conjunction searches has been found to come with age (Hommel et al., 2004). This age-related slowing of reaction time has been found to be a result of differences in search strategy, where older adults tend to search more exploitatively, while younger adults tend to search more exploratively (Wiegand et al., 2019; Wiegand & Wolfe, 2021). The previous studies using the hybrid foraging task have come to these conclusions by comparing a sample of older adults with a sample of younger adults. The present study finds these same effects within a sample of older adults (aged 65-86), indicating that the age-related changes in search strategy and reaction times can be seen even within the 20 years spanned in this sample. These results indicate that if the hybrid foraging task is to be used as a clinical assessment tool, it is necessary to have comparison data for age groups of smaller intervals in order to ensure that the patients' performance is being compared to the performance of a control group close to their own age.

False alarms

In order to investigate how many distractor objects were wrongly collected, the average number of false alarms was also calculated. When looking at the average number of false alarms in each of the sixteen sections of the screen, a higher rate of false alarms was collected in the middle four sections of the screen. This correlates with the pattern found regarding the number of valid clicks performed across the screen. These results indicate that the higher number of false alarms in the center may be a direct result of more clicks being performed in the center of the screen in general.

The number of false alarms clicked in relation to all clicked objects, also called the false alarm rates, found in all three experiments of this study are higher than those previously found in a similar age group using the same hybrid foraging task. Wiegand and colleagues (2019) tested a sample of 12 older adults with a mean age of 72,5 years (*SD* = 5,35). In their sample, the false alarm rate was approximately 0,01 when using the same amount of target objects as this study. The average false alarm rate found in the third experiment done in this study was 0,03 (*SD*= 0,03). The marginally older sample used in the third experiment of this study is not likely to be the cause of this difference, as age does not appear to influence the false alarm rate (Madden et al., 1999). However, since the standard deviation found in the third experiment is large enough to also encompass the average found in prior research, this difference in average false alarm rate cannot be said to be statistically significant.

Having many false alarms could be an indicator that the participant in question does not fully remember their target objects. It could potentially also be understood as an indicator of allocentric neglect, where the participant only attends to one half of each object. This could cause the participant to be unable to recognize the target object and erroneously click distractor objects instead. The interpretation of false alarms in the hybrid foraging task for a patient with suspected visuospatial neglect is something that would be relevant to investigate further in future research. Regardless of the interpretation, it is relevant to note that in this present study, one participant did have a large number of false alarms. In Experiment 1, Participant 1 had a false alarm rate of 0,11, and in Experiment 2 the same participant had a false alarm rate of 0,29. This is significantly higher than the average false alarm rate of 0,03 (*SD* = 0,03) found in the third experiment. While these results appear vastly different, it is not suitable to hypothesize an underlying cognitive deficit based solely on this study. Instead, the entirety of the testing situation needs to be taken into account in order to further understand these results. Perhaps the large number of false alarms should instead be seen as an indicator that the participant was nervous in the testing situation or that they did not fully understand the instructions of the study. Because of the multitude of possible explanations, this study will not attempt to further understand the underlying causes of the large number of false alarms produced by Participant 1.

Uncollected targets

The average number of uncollected targets was also investigated for each of the three experiments done in this study. The larger sample tested in experiment three left an average of 3,39 uncollected target objects behind when moving to the next patch in block one and 3,22 uncollected target items in block two. It is possible that a larger number of target objects left behind in a patch could be an indicator that some target types have not been collected at all, and possibly forgotten. On the other hand, consistently leaving no target objects behind can be seen as an indicator of an exhaustive search strategy, where the participant aims to empty each patch of all target items before moving to the next patch.

However, the validity of this measure is called into doubt by the statements given by the participants on the questionnaire. When asked if they had any additional comments to the task, four participants mentioned that they had moved to the next patch by accident at least one time. This happened when they were attempting to collect a target object near the “next” button on the screen, and accidentally clicked the button. This means that sometimes, the move to the next patch was unintentional, and it was therefore not by choice that they left that amount of uncollected targets in the previous patch.

First and last object picked

Another pattern that could be seen in the results of the third experiment, was regarding where the first target object in each valid patch is collected. The apparent tendency to collect the first target object on the left side of the screen was somewhat predicted by the previous research connecting search patterns to reading directionality. According to this research, the initial scanning strategy of left-to-right readers would be drawn to the upper left part of the screen. In the data from Experiment 3 of this current study, there does not appear to be a specific preference for the upper part of the screen when selecting the first target object in a new patch. However, it does appear that there is a tendency to select the first target object on the left side of the screen. All participants included in this study were from countries where the reading direction in the native language is left to right. Based on this, it can be hypothesized that the effects of reading direction of scanning strategy are contributing to the tendency to pick the first target in a new patch on the left side of the screen.

Another factor biasing where the first target object in a new patch is collected is likely to be the last point of visual fixation (Wolfe, 2021). Considering that moving to the next patch can only be done by clicking the "next" button, it can be assumed that this button was a point of visual fixation. As can be seen in Figure 20, the object collection appears to be more densely centered around the next button for the first collected object, where the last point of visual fixation is thought to be the next button. Additionally, the pattern of target object collections seems to be more dispersed in the graph showing the placement of the last object collected in each patch, which is consistent with the previously mentioned hypothesis, as the last point of visual fixation is not set for the last collected target in each patch.

So given these theoretical understandings of the apparent pattern, it is relevant to wonder why the pattern seen for the first click in each patch is not more uniform, given that there are also collected objects to the right of the center and toward the edges of the screen. One possibility is that the features of the objects may have affected the search. The target objects and distractor objects used for each participant are selected at random from the database of 1,922 possible objects. In the third experiment of this present study, five participants spontaneously reported in the questionnaire that some objects were easier to find than others based on their color. For example, a brightly colored blue target object would be easy to find in a patch with no other blue objects. In these instances, the hybrid foraging task is reminiscent of a simple feature search, where some target types pop out automatically based on bottom-up attentional processes. It is unclear if and how this has affected the results and reaction times of participants, but it is plausible that a feature search could disturb the expected search pattern by drawing automatic attention to another area.

The influence of visual set size

The hybrid foraging task used in the present study presented the participants with patches with a visual set size of either 50 or 100 objects. While the average rate of collection was calculated for all patches in a block, the instantaneous rates of collection was assessed separately for each visual set size, in order to compare how the number of objects shown in a patch affects foraging behavior. The instantaneous rates of collection were calculated for the last five reverse clicks of both blocks, giving a total of ten points where the instantaneous rates of the patches with the smaller visual set size can be compared to the instantaneous rates of the patches with the larger visual set size. In six out of these ten points, the instantaneous rate of collection was higher in the visual set size of 50 objects. This means that in general the participants earned more points for each second spent searching in the patches with fewer items. However, this also means that the instantaneous rates of collection were higher in the visual set size of 100 objects for four of these comparison-points.

Current research on the topic would predict that having more distractors in conjunction searches would increase reaction times on the task (Treisman & Gelade, 1980). Since 70% of the targets shown at the beginning of a new patch will always be distractors, this means that patches with a higher visual set size will consequently also have a larger number of distractors. This effect has been replicated in older adults as well, finding that the reaction times of older adults are especially affected by a task having a large number of distractors (Hommel et al., 2004). While the majority of the findings from this present study are in line with the expected results, the effect found here is not very convincing, as only six out of ten comparison points support this. A satisfactory explanation for this inconclusive result does not seem to be available within the existing theoretical background or the testing situation. However, while the results found in this study appear somewhat inconclusive, they are still tending toward the direction predicted by the previous research.

Further investigation into the effect of visual set size would be relevant in order to better understand how the number of objects in a patch affects control participants. If the hybrid foraging task is to be used as a tool for assessment of visuospatial neglect, then this knowledge would allow for an evaluation of whether a patient deviates from the expected effect of visual set size. This is relevant to understand because the number of distractors, and thereby the visual set size, is known to affect the visual search of patients with visuospatial neglect. It has previously been found that each distractor in the contralesional side, will triple the search time when a patient with visuospatial neglect is searching for a target in the ipsilesional side (Eglin et al., 1989). Drawing on this, it is likely that patients with neglect would have a harder time compensating for their deficits in tasks with more distractors. This means that a patient with visuospatial neglect may perform differently on the patches with the large visual set size than on patches with the small visual set size. In order to evaluate if this difference in performance is meaningful, it is first relevant to understand if the performance of neurologically healthy adults differs between the two visual set sizes.

Target types

The hybrid foraging task used in the study requires participants to be able to keep their eight target objects in their memory. By comparing older adults' performance on the hybrid foraging task when asked to remember a varying number of target objects, it has previously been found that the memory capacity required to perform the hybrid foraging task does not deteriorate with age (Wiegand et al., 2019).

So, while the memory capacities to perform the hybrid foraging task are a necessary prerequisite, the task itself, as performed in this study, does not appear to be a good measure of memory. 30% of the participants in the third experiment did not search for all eight target objects, with 7,5% omitting to collect two of their eight target objects throughout the entire hybrid foraging task. While it is tempting to use these numbers as an indicator for the normal amount of omitted target types, this would not be a transparent measure, since the participants were not informed in the instructions to the task that collecting all eight target objects was a goal. One participant specifically reported in the questionnaire that there were some objects that they were almost certain were a target object, but they never chose this object because they did not want to risk losing the points, and instead estimated that it would be faster for them to select only the "safe" targets that they were sure of. Conversely, other participants reported checking several distractor types to see if they were one of their target objects. This was done by clicking on a given object and receiving feedback on whether it was a target or distractor (as shown in Figure 5). For these reasons, the measure of how many of the eight target types were collected by each participant throughout the hybrid foraging task will not be used as an indicator of how many completely omitted target types are within the expected parameters for future testing on patients with visuospatial neglect.

Optimal foraging behavior

In the following sections, the optimal foraging behavior found in the present study will be compared to previous research on a similar sample of older adults. The most comparable study was done by Wiegand and colleagues (2019) on a sample of 12 older adults who performed the same hybrid foraging task as used in this study. While this present study had participants perform two blocks of the task, each terminating when the participants reached 500 points, the study by Wiegand and colleagues (2019) asked participants to perform four blocks of 1000 points each using a varying number of target objects.

For the blocks using the same amount of target objects as this present study, Wiegand and colleagues (2019) found that the instantaneous rates of collection for their participants dropped below the average rate between the fourth and the fifth reverse click. In comparison, the instantaneous rates of the participants included in the third experiment of this present study dropped below the average rate of collection between the first and second reverse click for three out of four possible conditions. The instantaneous rate for the remaining condition (block two, visual set size 50) did not drop below the average rate of collection for the block at any point. Looking at this, the foraging behavior seen in this study appears to be less exhaustive, and thereby more optimal than what was previously found in this age group.

When comparing the average rate found in this experiment with the average rate found in the study by Wiegand and colleagues (2019), a similar pattern appears. The third experiment done in this study found average rates of collection of 1,17 points per second in the first block and 1,25 points in the second block. For comparison, the study by Wiegand and colleagues (2019) found that their sample of older adults had an average rate of collection of 0,45 items per second. Seeing as their target items all had a value of two points, this leads to an average rate of 0,9 points per second. In addition to foraging more optimally, the participants in the third experiment of this study also appear to forage more efficiently than would be suggested by previous research. There are two notable differences between this study and the previous study that could possibly explain this divergence. Firstly, each participant needed to collect four times as many points in the previous experiment, as they did in this experiment. Secondly, and most importantly, in this present study the hybrid foraging task was performed on a touchscreen tablet outside the laboratory, while the previous study tested the participants on a stationary computer in a laboratory, where objects were collected by clicking a mouse. It is possible, maybe even likely, that the ability to collect target objects using a touchscreen rather than a mouse may be the underlying reason for the increase in collection rate seen in this study. This is supported by the finding that using a touchscreen instead of a mouse decreased reaction time by 35% for a sample of older adults (Findlater et al., 2013). This could explain why the number of points collected per second was higher for this study than previous research using the hybrid foraging task would predict. Taken together, these findings indicate that when taking the changed answering format into account, the foraging behavior found in this study is comparable to foraging behavior found in a sample of American older adults.

Potential limitations of the hybrid foraging task

The following sections will evaluate the potential of the hybrid foraging task as a bedside tool, in the light of the results from this study, as well as discuss potential limitations of the paradigm. This study has been the first time that the hybrid foraging task was performed on a touchscreen tablet. The appropriateness of testing the sample of older adults using a tablet was assessed, by asking the participants to report their own estimation of their ability to use a touchscreen on a Likert scale, ranging from very poor to very good (see Appendix B). Here no participants reported having poor or very poor touchscreen abilities. Instead, 60% of participants reported being good at using a touchscreen, 18% reported being very good, while 23% reported being neither good nor bad at it. This indicates that using a tablet as the instrument used to measure hybrid foraging behavior is appropriate even in the sample of older adults. This is also indicated by the fact that both participants from the first two experiments, as well as 14 participants from the third experiment, provided unsolicited feedback that they found the task to be entertaining and enjoyable. This suggests that the task was accessible, and that both the task itself and the fact that it was performed on a tablet was not overwhelming for the sample of older adults. In summary, the hybrid foraging task appears to be acceptable to use on a tablet as a bedside test.

While the hybrid foraging task used in this study is a relatively simple task, producing many relevant outcome measures for each participant, it is relevant to note that it takes on average 17,5 minutes of concentrated work for healthy adults to complete this task. Because it is commonly known that patients who have suffered brain injury fatigue more easily than healthy controls (LaChapelle & Finlayson, 1998), this could prove to be an issue for some patients. However, the ability to take a short break between the two blocks in the task can be seen as a mediating factor, making the hybrid foraging task more accessible.

Another possible limitation to using the hybrid foraging task as a tool for assessment of visuospatial neglect, is that the selection of objects for each participant is not controlled for. This is demonstrated by the fact that two participants in the third experiment of this study commented in their questionnaire that they were occasionally shown a distractor object that looked very similar to one of their target objects. This may have caused unnecessary confusion for these two participants and it would be advisable to incorporate controls for this in future uses of the hybrid foraging task.

Similarly, the results of foraging behavior, patch leaving time and number of uncollected targets were most likely unintentionally influenced by the fact that at least four participants clicked the “next” button accidentally while still collecting targets in the current patch. While there is no obvious way to correct this for future uses of the hybrid foraging task, it is relevant to be aware of as it has the potential to affect the outcome measures taken from the task.

Ultimately, the hybrid foraging task used in this study is a test of visual and visuospatial attention that appears to be suitable to perform on a tablet. Being able to use the hybrid foraging task on a table enables bedside testing using the task. However, some amendments are still needed in order to optimize the hybrid foraging task as a bedside test.

Conclusion

The aim of this study has been to determine if the hybrid foraging task can be used as a bedside tool for assessment of visual attention. Additionally, this study aimed to gather data on a sample of healthy older adults in order to determine what patterns can be expected in performance on the hybrid foraging task. The motivation for this was to lay the groundwork for determining if the hybrid foraging task could potentially be used as an assessment of visuospatial neglect in the future. In order to do this, three experiments were performed.

The results from these three experiments, as well as the feedback from the participants demonstrate that the hybrid foraging task can be made available for use outside of the laboratory setting, by having participants perform the task on a tablet with a touchscreen. Furthermore, the feedback and findings indicate that the hybrid foraging task, including the instructions, duration and demands of the task, were appropriate for a sample of older Danish adults.

Contrary to indications from the first experiment, performance for each of the two blocks in the hybrid foraging task do not appear to be significantly different when tested on a larger sample of older adults. Furthermore, the results of the experiments done in this study indicate that, when moving to a new patch, the first target object is most likely to be collected from the left side and near the center of the screen. This tendency to collect the first target object on the left side and close to the middle of the screen is believed to be influenced by reading direction as well as the proximity to the "next" button. Additionally, the results of the experiments suggest that there is a naturally occurring pattern in the spatial distribution of valid clicks across the screen. While there were no large gaps in the density of object collection throughout the screen, this pattern suggests that most objects are collected in the middle of the screen and less objects are collected in the four corners of the screen. The patterns described here are relevant to take note of, due to their potential implications if the hybrid foraging task is used as an assessment tool of visuospatial neglect. In order to determine if there are deviations in the patients' visual attention, as measured by the hybrid foraging task, it is first necessary to know what findings can be expected.

When testing a larger sample of older Danish adults, a negative relationship was found between age and performance on the hybrid foraging task. While this negative relationship has also previously been found, this study contributes by replicating this finding within the sample of older adults tested here. This means that the age-related decline in performance on the hybrid foraging task can also be seen within the span of relatively few years. Furthermore, the results from this study indicate that, after controlling for the differences in answering format, the foraging measures found in this sample of older adults tested in Denmark is comparable to the sample of older adults previously tested in America.

This paper has investigated the added measure of spatial placement as well as the use of the hybrid foraging task as a bedside test, with the aim of using the hybrid foraging task as a tool for assessment of visuospatial neglect in the future. However, there are still numerous possibilities for future research using the hybrid foraging task. At this point, the idea that the hybrid foraging task could be a good way of assessing visuospatial neglect is still only a theoretical one. The main aim of future research using the hybrid foraging task would be to determine if the task is able to effectively detect visuospatial neglect in patients, and if the hybrid foraging task is as sensitive a measure of visuospatial neglect as hypothesized.

References

American Psychological Association. (2023). Attention. *In APA dictionary of psychology*. https://dictionary.apa.org/attention

Appelros, P. (2007). Prediction of length of stay for stroke patients. *Acta Neurologica Scandinavica*, *116*(1), 15-19. https://doi.org/10.1111/j.1600-0404.2006.00756.x

Azouvi, P., Marchal, F., Samuel, C., Morin, L., Renard, C., Louis-Dreyfus, A., Jokie, C., Wiart, L., Pradat-Diehl, P., Deloche, G., & Bergego, C. (1996). Functional consequences and awareness of unilateral neglect: Study of an evaluation scale. *Neuropsychological Rehabilitation*, *6*(2), 133-150. https://doi.org/10.1080/713755501

Azouvi, P., Samuel, C., Louis-Dreyfus, A., Bernati, T., Bartolomeo, P., Beis, J. M., Chokron, S., Leclercq, M., Marchal, F., Martin, Y., de Montety, G., Olivier, S., Perennou, D., Pradat-Diehl, P., Rode, G., Siéroff, E., Wiart, L., & Rousseaux, M. (2002). Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke. *Journal of Neurology, Neurosurgery and Psychiatry*. *73*(2), 160–166. https://doi.org/10.1136/jnnp.73.2.160

Barrett, A. M., Buxbaum, L. J., Coslett, H. B., Edwards, E., Heilman, K. M., Hillis, A. E., Milberg, W. P., & Robertson, I. H. (2006). Cognitive rehabilitation interventions for neglect and related disorders: moving from bench to bedside in stroke patients. *Journal of cognitive neuroscience*, *18*(7), 1223-1236. https://doi.org/10.1162/jocn.2006.18.7.1223

Bisiach, E., & Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex*, *14*(1), 129-133. https://doi.org/10.1016/S0010-9452(78)80016-1

Bisiach, E., Perani, D., Vallar, G., & Berti, A. (1986). Unilateral neglect: Personal and extra-personal. *Neuropsychologia*, *24*(6), 759-767. https://doi.org/10.1016/0028-3932(86)90075-8

Bonato, M. (2012). Neglect and extinction depend greatly on task demands: A review. *Frontiers in human neuroscience*, *6*, Article 195. https://doi.org/10.3389/fnhum.2012.00195

Bowen, A., McKenna, K., & Tallis, R. C. (1999). Reasons for variability in the reported rate of occurrence of unilateral spatial neglect after stroke. *Stroke*, *30*(6), 1196–1202. https://doi.org/10.1161/01.STR.30.6.1196

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences*, *105*(38), 14325-14329. https://doi.org/10.1073/pnas.0803390105

Brain, W. R. (1941). Visual disorientation with special reference to lesions of the right hemisphere. *Brain*, *64*, 244-272. https://doi.org/10.1093/brain/64.4.244

Bramão, I., Mendonça, A., Faísca, L., Ingvar, M., Petersson, K. M., & Reis, A. (2007). The impact of reading and writing skills on a visuo-motor integration task: A comparison between illiterate and literate subjects. *Journal of the International Neuropsychological Society*, *13*(2), 359-364. http://doi.org/10.1017/S1355617707070440

Breedlove, S. M., & Watson, N. V. (2017). *Behavioral Neuroscience*. (8th ed.). Oxford University Press. (Chapter 18, pp. 573-608)

Broadbent, D. E. (1958). *Perception and Communication*. Pergamon Press. (Chapter 9, pp. 210-244)

Carrasco, M., & McElree, B. (2001). Covert attention accelerates the rate of visual information processing. *Proceedings of the National Academy of Sciences*, *98*(9), 5363-5367. https://doi.org/10.1073/pnas.081074098

Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. *Theoretical population biology*, *9*(2), 129-136. https://doi.org/10.1016/0040-5809(76)90040-x

Chen, P., Hreha, K., Fortis, P., Goedert, K. M., & Barrett, A. M. (2012). Functional assessment of spatial neglect: a review of the Catherine Bergego scale and an introduction of the Kessler foundation neglect assessment process. *Topics in stroke rehabilitation*, *19*(5), 423-435. https://doi.org/10.1310/tsr1905-423

Chen, P., McKenna, C., Kutlik, A. M., & Frisina, P. G. (2013). Interdisciplinary communication in inpatient rehabilitation facility: Evidence of under-documentation of spatial neglect after stroke. *Disability and Rehabilitation*, *35*(12), 1033–1038. https://doi.org/10.3109/09638288.2012.717585

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the acoustical society of America*, *25*(5), 975-979. https://doi.org/10.1121/1.1907229

Connor, C. E., Egeth, H. E., & Yantis, S. (2004). Visual attention: bottom-up versus top-down. *Current biology*, *14*(19), 850-852. https://doi.org/10.1016/j.cub.2004.09.041

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3*, 201-215. https://doi.org/10.1038/nrn755

Corbetta, M., & Shulman, G. L. (2011). Spatial neglect and attention networks. *Annual review of neuroscience, 34*, 569-599. https://doi.org/10.1146/annurev-neuro-061010-113731

Davis, E. T., & Palmer, J. (2004). Visual search and attention: an overview. *Spatial Vision, 17*(4-5), 249-255. https://doi.org/10.1163/1568568041920168 de Liaño, B. G. G., Quirós-Godoy, M., Pérez-Hernández, E., Cain, M., & Wolfe, J. (2018). Understanding visual search and foraging in cognitive development. *Journal of Vision*, *18*(10), 635-635. https://doi.org/10.1167/18.10.635

de Liaño, B. G. G., & Wolfe, J. M. (2022). The FORAGEKID Game: Hybrid-Foraging as a new way to study aspects of executive function in development. *Cognitive Development*, *64*, Article 101233. https://doi.org/10.1016/j.cogdev.2022.101233

Demeyere, N., & Gillebert, C. R. (2019). Ego-and allocentric visuospatial neglect: Dissociations, prevalence, and laterality in acute stroke. *Neuropsychology*, *33*(4), 490-498. https://doi.org/10.1037/neu0000527

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological review*, *70*(1), 80–90. https://doi.org/10.1037/h0039515

Driver, J., & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition*, *79*(1-2), 39-88. https://doi.org/10.1016/S0010-0277(00)00124-4

Egeth, H. E. (1966). Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics*, *1*, 245-252. https://doi.org/10.3758/BF03207389

Eglin, M., Robertson, L. C., & Knight, R. T. (1989). Visual search performance in the neglect syndrome. *Journal of Cognitive Neuroscience*, *1*(4), 372-385. https://doi.org/10.1162/jocn.1989.1.4.372

Ehinger, K. A., & Wolfe, J. M. (2016). When is it time to move to the next map? Optimal foraging in guided visual search. *Attention, Perception, & Psychophysics*, *78*, 2135-2151. https://doi.org/10.3758/s13414-016-1128-1

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & psychophysics*, *40*(4), 225-240. https://doi.org/10.3758/BF03211502

Esterman, M., & Rothlein, D. (2019). Models of sustained attention. *Current opinion in psychology*, *29*, 174-180. https://doi.org/10.1016/j.copsyc.2019.03.005

Evald, L., Wilms, I., & Nordfang, M. (2021). Assessment of spatial neglect in clinical practice: A nationwide survey. *Neuropsychological Rehabilitation*, *31*(9), 1374-1389. https://doi.org/10.1080/09602011.2020.1778490

Ferber, S., & Karnath, H. O. (2001). How to assess spatial neglect - Line bisection or cancellation tasks?. *Journal of clinical and experimental neuropsychology*, *23*(5), 599-607. https://doi.org/10.1076/jcen.23.5.599.1243

Fernandez-Duque, D., & Johnson, M. L. (2002). Cause and effect theories of attention: The role of conceptual metaphors. *Review of general psychology*, *6*(2), 153-165. https://doi.org/10.1037/1089-2680.6.2.153

Filley C. M. (2002). The neuroanatomy of attention. *Seminars in speech and language*, *23*(2), 89–98. https://doi.org/10.1055/s-2002-24985

Filley, C. M., & Cullum, C. M. (1994). Attention and vigilance functions in normal aging. *Applied neuropsychology*, *1*(1-2), 29-32. https://doi.org/10.1080/09084282.1994.9645327

Findlater, L., Froehlich, J. E., Fattal, K., Wobbrock, J. O., & Dastyar, T. (2013). Age-related differences in performance with touchscreens compared to traditional mouse input. *Conference on Human Factors in Computing Systems – Proceedings*, 343-346. http://doi.org/10.1145/2470654.2470703.

Fortenbaugh, F. C., DeGutis, J., Germine, L., Wilmer, J. B., Grosso, M., Russo, K., & Esterman, M. (2015). Sustained attention across the life span in a sample of 10,000:

Dissociating ability and strategy. *Psychological science*, *26*(9), 1497-1510. https://doi.org/10.1177/0956797615594896

Friedenberg. (2013). *Visual attention and consciousness*. Psychology Press. https://doi.org/10.4324/9780203073858 (Chapter 7, pp. 63-73)

Gainotti, G., Messerli, P., & Tissot, R. (1972). Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesions. *Journal of Neurology, Neurosurgery & Psychiatry*, *35*(4), 545-550. http://doi.org/10.1136/jnnp.35.4.545

Gialanella, B., Monguzzi, V., Santoro, R., & Rocchi, S. (2005). Functional recovery after hemiplegia in patients with neglect: the rehabilitative role of anosognosia. *Stroke*, *36*(12), 2687-2690. https://doi.org/10.1161/01.STR.0000189627.27562.c0

Gottesman, R. F., Kleinman, J. T., Davis, C., Heidler-Gary, J., Newhart, M., Kannan, V., & Hillis, A. E. (2008). Unilateral neglect is more severe and common in older patients with right hemispheric stroke. *Neurology*, *71*(18), 1439-1444. https://doi.org/10.1212/01.wnl.0000327888.48230.d2

Grattan, E. S., Skidmore, E. R., & Woodbury, M. L. (2018). Examining anosognosia of neglect. *OTJR: occupation, participation and health*, *38*(2), 113-120. https://doi.org/10.1177/1539449217747586

Grattan, E. S., & Woodbury, M. L. (2017). Do neglect assessments detect neglect differently? *American Journal of Occupational Therapy*, *71*, Article 7103190050. https://doi.org/10.5014/ajot.2017.025015

Halligan, P. W. & Marshall, J. C. (1993). The History and Clinical Presentation of Neglect. In Robertson, I. H. & Marshall, J. C. (Eds.), *Unilateral Neglect: Clinical and Experimental Studies* (pp. 3-26). Lawrence Erlbaum Associates, Inc. https://doi.org/10.4324/9780203765258

Halligan, P. W., Marshall, J. C., & Wade, D. T. (1989). Visuospatial neglect: underlying factors and test sensitivity. *The Lancet*, *334*(8668), 908-911. https://doi.org/10.1016/S0140-6736(89)91561-4

Hasegawa, C., Hirono, N., & Yamadori, A. (2011). Discrepancy in unilateral spatial neglect between daily living and neuropsychological test situations: a single case study. *Neurocase*, *17*(6), 518-526. https://doi.org/10.1080/13554794.2010.547506

Heilman, K. M., Valenstein, E., & Watson, R. T. (1984). Neglect and related disorders. *Seminars in Neurology, 4*(2), 209-219. http://doi.org/10.1055/s-2008-1041551

Hillis, A. E., Wityk, R. J., Barker, P. B., Beauchamp, N. J., Gailloud, P., Murphy, K., Cooper, O., & Metter, E. J. (2002). Subcortical aphasia and neglect in acute stroke: the role of cortical hypoperfusion. *Brain*, *125*(5), 1094-1104. https://doi.org/10.1093/brain/awf113

Hommel, B., Li, K., & Li, S. C. (2004). Visual search across the life span. *Developmental psychology*, *40*(4), 545-558. https://doi.org/10.1037/0012-1649.40.4.545

Humphrey, D. G., & Kramer, A. F. (1997). Age differences in visual search for feature, conjunction, and triple-conjunction targets. *Psychology and Aging*, *12*(4), 704–717. https://doi.org/10.1037/0882-7974.12.4.704

Hyman Jr, I. E., Boss, S. M., Wise, B. M., McKenzie, K. E., & Caggiano, J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Applied Cognitive Psychology*, *24*(5), 597-607. https://doi.org/10.1002/acp.1638

Ischebeck, A., Hiebel, H., Miller, J., Höfler, M., Gilchrist, I. D., & Körner, C. (2021). Target processing in overt serial visual search involves the dorsal attention network: A fixation-based event-related fMRI study. *Neuropsychologia*, *153,* Article 107763. https://doi.org/10.1016/j.neuropsychologia.2021.107763

Ishiai, S., Koyama, Y., Seki, K., & Nakayama, T. (1998). What Is Line Bisection in Unilateral Spatial Neglect?: Analysis of Perceptual and Motor Aspects in Line Bisection Tasks. *Brain and Cognition*, *36*(3), 239-252. https://doi.org/10.1006/brcg.1998.0980

James, W. (1950). *The Principles of Psychology* (Vol. 1). Dover Publications (Original work published 1890) (pp. 486-556)

Kelly-Hayes, M. (2010). Influence of age and health behaviors on stroke risk: Lessons from longitudinal studies. *Journal of the American Geriatrics Society*, *58,* 325-328. https://doi.org/10.1111/j.1532-5415.2010.02915.x

Kendall, P. C., & Sheldrick, R. C. (2000). Normative data for normative comparisons. *Journal of Consulting and Clinical Psychology*, *68*(5), 767–773. https://doi.org/10.1037/0022-006X.68.5.767

Kosovicheva, A., Alaoui-Soce, A., & Wolfe, J. M. (2020). Looking ahead: When do you find the next item in foraging visual search?. *Journal of vision*, *20*(2), 3-3. https://doi.org/10.1167/jov.20.2.3

Kristjánsson, Á., Jóhannesson, Ó. I., & Thornton, I. M. (2014). Common attentional constraints in visual foraging. *PloS one, 9*(6), Article 100752. https://doi.org/10.1371/journal.pone.0100752

Kristjánsson, T., Thornton, I. M., Chetverikov, A., & Kristjánsson, Á. (2020). Dynamics of visual attention revealed in foraging tasks. *Cognition*, *194*, Article 104032. https://doi.org/10.1016/j.cognition.2019.104032

LaChapelle, D. L., & Finlayson, M. A. J. (1998). An evaluation of subjective and objective measures of fatigue in patients with brain injury and healthy controls. *Brain injury*, *12*(8), 649-659. https://doi.org/10.1080/026990598122214

Lezak, M. D., Howieson, D. B., Bigler, E. D., & Tranel, D. (2012). *Neuropsychological assessment* (5th ed.). Oxford University Press. (Chapter 10, pp. 427-465)

Luck, S. J., Hillyard, S. A., Mangun, G. R., & Gazzaniga, M. S. (1989). Independent hemispheric attentional systems mediate visual search in split-brain patients. *Nature*, *342*(6249), 543–545. https://doi.org/10.1038/342543a0

Madden, D. J., Whiting, W. L., Spaniol, J., & Bucur, B. (2005). Adult Age Differences in the Implicit and Explicit Components of Top-Down Attentional Guidance During Visual Search. *Psychology and Aging*, *20*(2), 317–329. https://doi.org/10.1037/0882-7974.20.2.317

Mancuso, M., Rosadoni, S., Capitani, D., Bickerton, W. L., Humphreys, G. W., De Tanti, A., Zampolini, M., Galardi, G., Caputo, M., De Pellegrin, S., Angelini, A., Bartalini, B., Bartolo, M., Carboncini, M. C., Gemignani, P., Spaccavento, S., Cantagallo, A., Zoccolotti, P., & Antonucci, G. (2015). Italian standardization of the apples cancellation test. *Neurological sciences*, *36*, 1233-1240. https://doi.org/10.1007/s10072-015-2088-2

Matlin, M. W. (2009). *Cognitive Psychology* (7th ed.). John Wiley & Sons. (Chapter 1, pp. 1-31; Chapter 3, pp- 65-92)

Melloni, L., van Leeuwen, S., Alink, A., & Müller, N. G. (2012). Interaction between bottom-up saliency and top-down control: how saliency maps are created in the human brain. *Cerebral cortex*, *22*(12), 2943-2952. https://doi.org/10.1093/cercor/bhr384

Menon, A., & Korner-Bitensky, N. (2004). Evaluating unilateral spatial neglect post stroke: working your way through the maze of assessment choices. *Topics in stroke rehabilitation*, *11*(3), 41-66. https://doi.org/10.1310/KQWL-3HQL-4KNM-5F4U

Mesulam, M. (2002). 2.1 Functional anatomy of attention and neglect: from neurons to networks. In Karnath, H. O., Milner, A. D., & Vallar, G. (Eds.), *The cognitive and neural bases of spatial neglect* (pp. 33-45). Oxford University Press.

Moray, N. (1959). Attention in Dichotic Listening: Affective Cues and the Influence of Instructions. *Quarterly Journal of Experimental Psychology*, *11*. 56-60. http://doi.org/10.1080/17470215908416289.

Mort, D. J., Malhotra, P., Mannan, S. K., Rorden, C., Pambakian, A., Kennard, C., & Husain, M. (2003). The anatomy of visual neglect. *Brain*, *126*(9), 1986-1997. https://doi.org/10.1093/brain/awg200

Muñoz-García, A., Cain, M., Wolfe, J., & de Liaño, B. G. G. (2018). Hybrid Foraging Performance is Related to Fluid Intelligence. *Journal of Vision*, *18*(10), 291-291. https://doi.org/10.1167/18.10.291

Na, D. L., Adair, J. C., Choi, S. H., Seo, D. W., Kang, Y., & Heilman, K. M. (2000). Ipsilesional versus contralesional neglect depends on attentional demands. *Cortex*, *36*(4), 455-467. https://doi.org/10.1016/S0010-9452(08)70532-X

Na, D. L., Adair, J. C., Williamson, D. J., Schwartz, R. L., Haws, B., & Heilman, K. M. (1998). Dissociation of sensory-attentional from motor-intentional neglect. *Journal of Neurology, Neurosurgery & Psychiatry*, *64*(3), 331-338. http://doi.org/10.1136/jnnp.64.3.331

Neisser, U. (1976). *Cognition and reality: principles and implications of cognitive psychology*. WH Freeman and Company. (Chapter 5, pp. 79-107)

Nordfang, M., & Nørby, S. (2017). *Kognitionspsykologi*. Samfundslitteratur. (Chapter 3, pp. 113-145)

Olivers, C. N., Huettig, F., Singh, J. P., & Mishra, R. K. (2014). The influence of literacy on visual search. *Visual Cognition*, *22*(1), 74-101. https://doi.org/10.1080/13506285.2013.875498

Papadatou-Pastou, M., Ntolka, E., Schmitz, J., Martin, M., Munafò, M. R., Ocklenburg, S., & Paracchini, S. (2020). Human handedness: A meta-analysis. *Psychological Bulletin*, *146*(6), 481-524. https://doi.org/10.1037/bul0000229

Pashler. (1998). *The psychology of attention*. MIT. (Chapter 2, pp. 37-100; Chapter 3, pp. 101-166)

Pineas, H. (1931). Ein fall von räumlicher orientierungsstörung mit dyschirie. *Zeitschrift für die gesamte Neurologie und Psychiatrie*, *133*(1), 180-195. https://doi.org/10.1007/BF02909922

Pitteri, M., Chen, P., Passarini, L., Albanese, S., Meneghello, F., & Barrett, A. M. (2018). Conventional and functional assessment of spatial neglect: Clinical practice suggestions. *Neuropsychology*, *32*(7), 835–842. https://doi.org/10.1037/neu0000469

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*(1), 3-25. https://doi.org/10.1080/00335558008248231

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of experimental psychology: General*, *109*(2), 160-174. https://doi.org/10.1037/0096-3445.109.2.160

Schendel, K. L., & Robertson, L. C. (2002). Using reaction time to assess patients with unilateral neglect and extinction. *Journal of Clinical and Experimental Neuropsychology*, *24*(7), 941-950. https://doi.org/10.1076/jcen.24.7.941.8390

Schneider, W., & Shiffrin, R. M., (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review*, *84*(2), 127-190. https://doi.org/10.1037/0033-295X.84.2.127

Stanczak, E. M., Stanczak, D. E., & Templer, D. I. (2000). Subject-selection procedures in neuropsychological research: A meta-analysis and prospective study. *Archives of* *clinical neuropsychology*, *15*(7), 587-601. https://doi.org/10.1016/S0887-6177(99)00049-9

Staub, B., Doignon-Camus, N., Bacon, E., & Bonnefond, A. (2014). Investigating sustained attention ability in the elderly by using two different approaches: Inhibiting ongoing behavior versus responding on rare occasions. *Acta psychologica*, *146*, 51-57. https://doi.org/10.1016/j.actpsy.2013.12.003

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the international neuropsychological society*, *8*(3), 448-460. http://doi.org/10.1017/S1355617702813248

Sundhedsstyrelsen & Dansk Råd for Genoplivning. (2020). *Faktaark: Stroke i Danmark.* https://www.sst.dk/-/media/Udgivelser/2020/Stroke/Faktaark-stroke.ashx?la=da&hash=5A3D3EF6673A8FE92810AED1827BF527C54826A4

Szczepanski, S. M., Pinsk, M. A., Douglas, M. M., Kastner, S., & Saalmann, Y. B. (2013). Functional and structural architecture of the human dorsal frontoparietal attention network. *Proceedings of the National Academy of Sciences*, *110*(39), 15806-15811. https://doi.org/10.1073/pnas.1313903110

Thomson, D. R., & Hasher, L. (2017). On the preservation of vigilant attention to semantic information in healthy aging. *Experimental Brain Research*, *235*, 2287-2300. https://doi.org/10.1007/s00221-017-4969-5

Treisman, A. M. (1964). Monitoring and storage of irrelevant messages in selective attention. *Journal of Verbal Learning and Verbal Behavior*, *3*(6), 449–459. https://doi.org/10.1016/S0022-5371(64)80015-3

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive psychology*, *12*(1), 97-136. https://doi.org/10.1016/0010-0285(80)90005-5

Tromp, E., Dinkla, A., & Mulder, T. (1995). Walking through doorways: An analysis of navigation skills in patients with neglect. *Neuropsychological Rehabilitation, 5*(4), 319-331. https://doi.org/10.1080/09602019508401475

Uddannelses- og Forskningsministeriet (n.d.). *Dansk-Engelsk Uddannelsesterminologi*. https://ufm.dk/uddannelse/anerkendelse-og-dokumentation/dokumentation/termbase

Vallar, G., & Perani, D. (1986). The anatomy of unilateral neglect after right-hemisphere stroke lesions. A clinical/CT-scan correlation study in man. *Neuropsychologia*, *24*(5), 609-622. https://doi.org/10.1016/0028-3932(86)90001-1

Vanier, M., Gauthier, L., Lambert, J., Pepin, E. P., Robillard, A., Dubouloz, C. J., Gagnon, R., & Joannette, Y. (1990). Evaluation of left visuospatial neglect: Norms and discrimination power of two tests. *Neuropsychology*, *4*(2), 87-96. https://doi.org/10.1037/0894-4105.4.2.87

Vossel, S., Geng, J. J., & Fink, G. R. (2014). Dorsal and ventral attention systems: distinct neural circuits but collaborative roles. *The Neuroscientist*, *20*(2), 150-159. https://doi.org/10.1177/1073858413494269

Watson, F. (1915). The father of modern psychology. *Psychological Review*, 22(5), 333-353. https://doi.org/10.1037/h0073231

Wiegand, I., Seidel, C., & Wolfe, J. (2019). Hybrid foraging search in younger and older age. *Psychology and Aging*, *34*(6), 805–820. https://doi.org/10.1037/pag0000387

Wiegand, I., & Wolfe, J. M. (2020). Age doesn’t matter much: Hybrid visual and memory search is preserved in older adults. *Aging, Neuropsychology, and Cognition*, *27*(2), 220-253. https://doi.org/10.1080/13825585.2019.1604941

Wiegand, I., & Wolfe, J. M. (2021). Target value and prevalence influence visual foraging in younger and older age. *Vision research*, *186*, 87-102. https://doi.org/10.1016/j.visres.2021.05.001

Wikman, A. S., Nieminen, T., & Summala, H. (1998). Driving experience and time-sharing during in-car tasks on roads of different width. *Ergonomics*, *41*(3), 358-372. https://doi.org/10.1080/001401398187080

Wolfe, J. M. (1992). The parallel guidance of visual attention. *Current Directions in Psychological Science*, *1*(4), 124-128. https://doi.org/10.1111/1467-8721.ep10769733

Wolfe, J. M. (2012). Saved by a log: How do humans perform hybrid visual and memory search?. *Psychological Science*, *23*(7), 698-703. https://doi.org/10.1177/0956797612443968

Wolfe, J. M. (2013). When is it time to move to the next raspberry bush? Foraging rules in human visual search. *Journal of vision*, *13*(3), Article 10. https://doi.org/10.1167/13.3.10

Wolfe, J. M. (2021). Guided Search 6.0: An updated model of visual search. *Psychonomic Bulletin & Review*, *28*(4), 1060-1092. https://doi.org/10.3758/s13423-020-01859-9

Wolfe, J. M., Aizenman, A. M., Boettcher, S. E., & Cain, M. S. (2016). Hybrid foraging search: Searching for multiple instances of multiple types of target. *Vision research*, *119*, 50-59. https://doi.org/10.1016/j.visres.2015.12.006

Wolfe, J. M., Cain, M. S., & Aizenman, A. M. (2019). Guidance and selection history in hybrid foraging visual search. *Attention, Perception, & Psychophysics*, *81*(3), 637-653. https://doi.org/10.3758/s13414-018-01649-5

Wolfe, J. M., Cain, M. S., & Alaoui-Soce, A. (2018). Hybrid value foraging: How the value of targets shapes human foraging behavior. *Attention, Perception, & Psychophysics*, *80*(3), 609-621. https://doi.org/10.3758/s13414-017-1471-x

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human* *perception and performance*, *15*(3), 419-433. https://doi.org/10.1037/0096-1523.15.3.419

Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). Rare items often missed in visual searches. *Nature*, *435*(7041), 439-440. https://doi.org/10.1038/435439a