University of Trento

Doctoral Thesis

The Effect of Aging on Object Representation

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Declaration

This dissertation is the result of my own work unless specifically indicated in the text as the outcome of a collaboration, or cited and acknowledged as a material from another source. It has not been previously submitted, in part or whole, to any university or institution for any degree, diploma, or other qualification.

Signed: 

Date: 17/12/2023

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Chapter 1

General Introduction

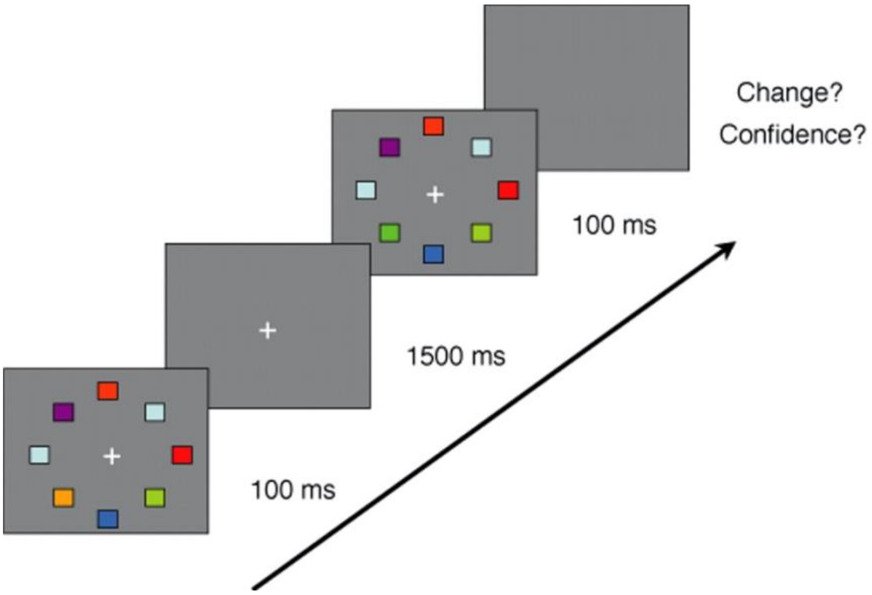
1. Introduction

As the median global age increases (World Health Organization, 2022), the importance of developing a comprehensive understanding of aging and its effects in cognition also increases. Two cognitive functions that older adults (OAs) are commonly found to demonstrate deficits are visual working memory (vWM) and attention, two domains that are also highly involved with one another (Naveh-Benjamin & Cowan, 2023). However, it is not always the case that OAs demonstrate age-deficits in tasks probing these domains (Souza, Frischkorn & Oberauer, 2023; see Holcomb, Tagliabue & Mazza, 2022 for a review in vWM and age-effects). For instance, it has been found that OAs indicated higher activation in brain areas including the dorsolateral prefrontal cortex when presented with a low load of verbal WM stimuli, whereas opposingly, young adults demonstrated higher activation only with a higher load of verbal stimuli. In the low load conditions, behavioral differences between the two age groups were limited, while in the high load conditions, OAs instead demonstrated impairments compared to young adults (see Reuter-Lorenz & Cappell, 2008). These results led to the conceptualization of the compensation-related utilization of neural circuits hypothesis (CRUNCH model) and as suggested by Reuter-Lorenz and Cappell (2008), postulate that OAs need to recruit more resources in order to perform similarly to their young adult counterparts, which is an effective mechanism when demands are low (low load condition described above), but are inefficient when demands are too difficult. Intact performances have also been exhibited in aging in visual WM tasks of the feature binding of objects (see Holcomb et al., 2022) as well as in the search for visual stimuli probing attention (see Wiegand & Wolfe, 2020). Therefore, further research examining the specifics of age-related preservations or impairments is warranted…

A typical paradigm for assessing vWM is the Change Detection Task (CDT; see Figure 1 from Wilken & Ma, 2004), in which an observer is presented with a series of elements in one screen; after a brief delay, observers must recall whether a change has occurred in the display (Luck & Vogel, 1997). Seminal studies investigating age-related effects in vWM using CDTs relied on the presentation of geometrical stimuli including colored dots (Ko et al., 2014). The typical finding is that OAs have a selective impairment: namely, their performance is worse than young adults only when there is a higher amount of items to retain and recall, suggesting a fewer amount of items that OAs can maintain in memory (Ko et al., 2014; Sander, Werkle-Bergner, & Lindenberger, 2011). Although these studies are informative in our understanding of cognition in older age, conclusions based on investigations using geometrical stimuli are ultimately limited in determining whether memory differences in aging are strictly a quantitative problem, or whether qualitative differences are also prevalent. This is a limitation that the current thesis will address.

Figure 1

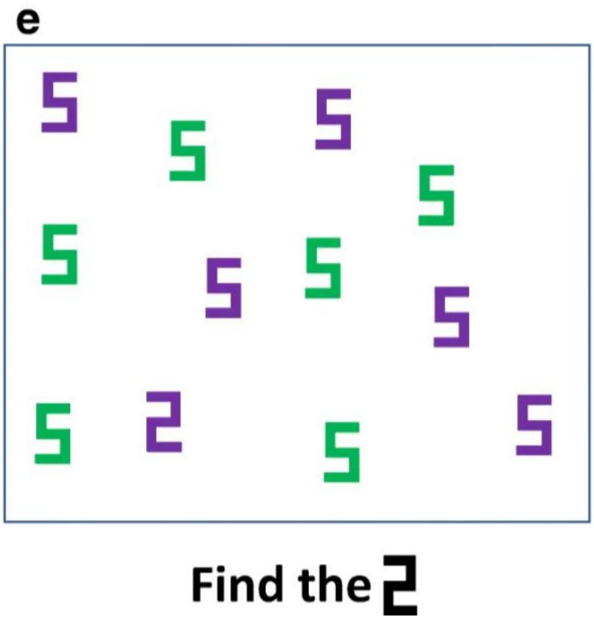
Change Detection Task from Wilken and Ma (2004)



As for the assessment of attention, a typical paradigm used is Visual Search (VST; see Figure 2 from Wolfe, 2021), in which subjects must detect the presence or absence of a predefined target presented amongst distractor items (Wolfe, 1994). There is a plethora of VST research using colored shapes, letters and oriented lines indicating that OAs demonstrate selective impairments when search is more difficult, such as when the target and distractor objects have more simple features in common (such as the same color or a similar line orientation), and when there is an increased amount of total items in the display (Plude & Doussard-Roosevelt, 1989).

Figure 2

Visual Search Example from Wolfe (2021)



In these seminal aging studies, the assumption that there is a quantitative problem that occurs throughout aging is persistent across both vWM and attention research fields. For example, if dots are the stimuli used in a task, then the natural take-away is that OAs have a smaller *amount* of dot representations that they can retain or recall. Relatedly, a similar conclusion can be derived from studies using multiple featured geometrical stimuli in VSTs. In VSTs, OA's demonstrate enhanced difficulties when one or more of the features comprising their target representation is in common with a distractor (Plude & Doussard-Roosevelt, 1989;

Scialfa, Esau, & Joffe, 1998), necessitating that the subject retains each relevant feature comprising the target, in order to be able to distinguish it from items containing similar features. Further reinforcing this quantitative problem, more age-related impairments are found when there is an increased amount of these distractors (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998).

Therefore, the question remains: is it strictly the amount of representations that lead to impaired age-related performances in cognitive tasks of vWM and attention, or does the content of the representations also change in aging?

Importantly, the investigation of whether it is strictly a fewer amount of items or representations that OAs can remember, or whether the content of the representation presented has an additive influence on age-related impairments, is restricted when using geometrical stimuli. Conversely, if more complex stimuli are used, one is able to probe whether it is not only the *amount*, but also the *content* of the object representation, that influences OA's performances. In the sense that one can compare between different types of manipulations of stimuli, for example real-world object stimuli, and probe whether OA's difficulties are the result of only more objects presented, or whether differences arise given the type of different manipulations of images. An effective manner in which to investigate this question is to investigate OA's performances in tasks probing vWM and attention using real-world objects. Not only are real-world objects more applicable to everyday situations, but research in young adults (YA) have found better cognitive performances in tasks using real-world objects as stimuli (Brady, Störmer, & Alvarez, 2016) and higher WMC for "meaningful" real-world objects, compared to ambiguous stimuli (Asp, Störmer, & Brady, 2021). Evidently, a shift to the use of real-world stimuli is pertinent in order to better understand how aging impairs multiple object processing. This thesis will address this question as to the possible influence of using real-world stimuli.

Probing both the quantity and the quality of representations and investigating possible changes in aging may suggest a more qualitative difference in cognitive decline that occurs throughout the discourse of aging. For instance, some studies have found qualitative differences in the manner in which OAs assess real-world scenes (Ramzaoui, Faure, & Spotorno, 2022), as well as an increased reliance on semantic features in aging in studies asking for the recall of more realistic objects (see Boutet, Dawod, Chiasson, Brown, & Collin, 2019; Koutstaal et al., 2003; Pidgeon & Morcom, 2014). These findings appear to suggest an interesting qualitative difference in cognitive aging that is separate from impairments due solely to a decreased amount of representations that can be remembered with increased age.

The following sections will be divided into first describing vWM decline in OAs, with a focus on our lack of an understanding as to whether the decline found in aging is related to the quantity or the content of memory items. The second section will then discuss seminal attention and aging studies and what remains to be understood concerning the influence of the content of object representations in VSTs, as well as the manner in which object representations are viewed in aging. Ocular measurements will then expand this discussion to a better understanding of how such real-world objects are assessed, that goes beyond accuracy and reaction time measurements.

Finally, it is worth considering that OAs demonstrate a reduced speed of processing in aging (Salthouse & Madden, 2008), and therefore these effects should be considered when interpreting the results of comparisons between young and OAs. In recent years, such effects are typically statistically controlled for (see Wiegand & Wolfe, 2020), however finding additional manners in which to test for specific age effects, and not a general slowing with age is of utmost importance. Further reinstating this point, Salthouse (2012) discusses older keyboard typists demonstrated overall slower reaction times relative to their younger typist counterparts, however indicated a better view of keystrokes and higher eye-hand spans, suggesting to Salthouse (2012) that older age was associated with skills specific to a task that lead to better performances. Evidently, it is important to consider how to test for age effects that are simply not a result of slowing in general, in order to determine what is intact and what is impaired in aging. Although this consideration is not the focus of the current thesis, future research in the field of aging should investigate further.

1.1 Aging and Visual Working Memory

Working Memory and Age-Related Decline

Working memory (WM) is the retention of information in order to perform a given task (Baddeley, 2000; Brady, Konkle, & Alvarez, 2011). Investigating the limited capacity of items held in WM, or working memory capacity, is one of the main focuses of WM research (Brady et al., 2011). Moreover, WM research is pertinent as this ability has been found to be highly associated with a range of other cognitive abilities including fluid intelligence (Fukuda, Vogel, Mayr, & Awh, 2010b). Even more precisely, previous findings of associations between abilities such as general intelligence and specifically the capacity of WM (WMC) have also been found (see Cowan et al., 2005), warranting a comprehensive understanding into the limited capacity nature of WM.

Given the significance of this cognitive ability, research investigating WM, as well as possible declines in the function, are of utmost importance. In line with this, WM has been shown to decline throughout the discourse of aging (Brockmole & Logie, 2013; Cabeza, Nyberg, Park, Reuter-Lorenz, & Lustig, 2016; Logie & Maylor, 2009), with OAs demonstrating lower WM performances than YAs (Ko et al., 2014; Sander et al., 2011). This lower WM performance is typically determined through lower capacity scores, in comparison to YAs, exhibited in tasks assessing WM abilities. However, the specifics of OA's lower WM abilities are less clear, predominantly whether lower age-related WM performances are solely the result of a lower number of items held in memory or, whether the contents of WM representations that OAs are maintaining are degraded. Since impairments in the content of WM representations maintenance have been proposed as markers for the diagnosis of Alzheimer's Disease (see Peich, Husain, & Bays, 2013 for a discussion), it is of utmost importance to understand more precisely the structure of WM representation abilities in healthy OAs. One of the main aims of the current thesis is to address whether WM abilities in aging are related to the number of items to recall, or dependent as well on the representational content.

In the following paragraph, I will discuss WM representations with relation to capacity limits. Due to the lack of research on the specifics of WMC limitations and representations in OAs, there will be a focus on discussing research that has been done in YAs within this topic. Following this, the limited research that has been done to conceptualize WM representations in OAs will also be touched on, along with considerations that could be given to investigate this topic in aging. Behavioral measurements that have shown promise for continuing this pertinent investigation will be reported, concluding with suggestions for future research within this topic. These suggestions pertain both to overall considerations that should be examined further for this research question, as well as specific considerations prevalent for assessing age-related declines in WM representations.

Working Memory Capacity in Young Adulthood: Is it Fixed or Flexible?

This section will delve into the discussion of the content of WM representations through presenting research in YAs due to the sparse amount of research on this topic specifically in OAs. Despite more research in YAs regarding WM content representations, there remains a significant amount of variation in findings, and resulting conclusions, across these multitude of studies. As such, the proceeding section of this review will discuss potential reasons underlying discrepant findings.

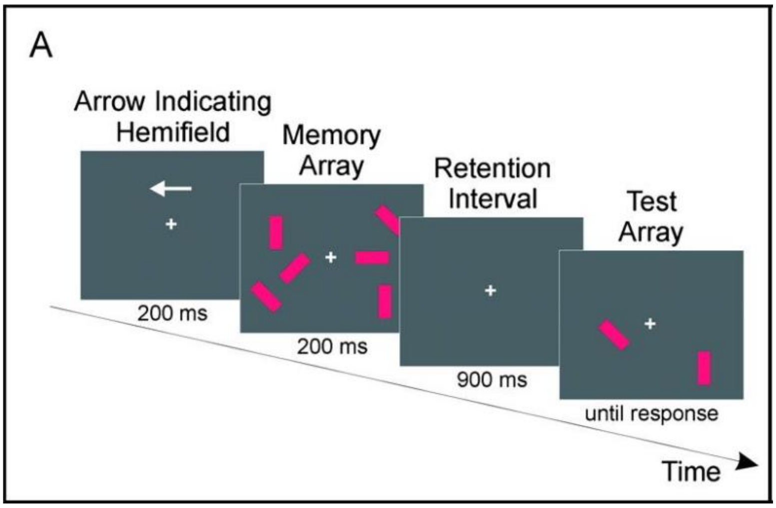
Within the WM research field, investigations of late have shifted from quantifying WMC in sole terms of a limited amount of items maintained to developing a better understanding of the content of the WM representations that are being stored (Brady et al., 2011). Specifically, research has focused on investigating whether WMC limits are defined by the number of items remembered, regardless of the content of the representations (Luck & Vogel, 1997), commonly referred to as a fixed slot capacity (see Bays, Catalao, & Husain, 2009; Eng, Chen, & Jiang, 2005; Ma, Husain, & Bays, 2014; Zhang & Luck, 2008 for a discussion). In opposition to this theory, other proposals have theorized that the content of the item that is meant to be maintained in WM places a constraint on capacity limits (Alvarez & Cavanagh, 2004). This suggests WM to be more of a flexible resource (Fukuda, Awh, & Vogel, 2010a), wherein more WM slots are allocated when the content of representation is less complex or contains fewer features to remember or, alternatively, less slots are allocated given the higher complexity of a representation or with more features to remember. Within this theory of WMC as a flexible resource, not only is it possible that, depending on the content of the WM representations, more or less slots may be allocated, but also, this flexibility would pertain to the resolution of the items, wherein it is possible an individual may retain a small amount of high-resolution representations, or alternatively, a large amount of low-resolution representations (see Zhang & Luck, 2008 for a discussion).

An important concept to consider within the topic of visual WM and the influence of simple or a conjunction of complex features is feature binding. Feature binding involves two main considerations: the binding of an object to where it was previously presented in a display (object-location binding), and the binding of two features that comprise an item (within-feature binding; see Chapter 2 below for a more thorough discussion). Feature binding necessitates focused attention in order to bind two or more features together, and then the item and its features are maintained in WM (Schneegans & Bays, 2019; Treisman, 1986). Typical experiments in this realm assess feature binding abilities in tasks measuring WM, in order to probe whether combined features comprising an object are maintained over a short period. Chapter 2 will present a discussion on the main effects of age on feature binding in visual WM. Importantly, feature binding has been used as a method to distinguish healthy OAs from both those with Alzheimer's disease (AD) and at vascular risk (Bika et al., 2021; Della Sala, Kozlova, Stamate, & Parra, 2018; Parra et al., 2009), instating the importance of investigating feature binding in healthy aging, in order to fully understand the trajectory of feature binding abilities throughout the discourse of aging.

As mentioned previously, a standard measurement of WM ability is the change detection paradigm (CDT; Luck & Vogel, 1997) in which an individual is presented with a display of a fixed number of objects; typically, colored squares, shapes or images, and then following a short delay the individual is asked to report whether there has been a change in the display. CDTs (preceded with an arrow indicating the appropriate hemifield to attend to; see Figure 3: adapted from the original; Jost, Bryck, Vogel, & Mayr, 2011) consist of an encoding (Memory Array), maintenance (Retention Interval) and retrieval stage (Test Array). It is important to note that the time of each presentation can vary depending on the aim of the experimental paradigm, although most are typically within a few hundred milliseconds similar to Jost et al. (2011; see Figure 3 Panel A). Each of these stages corresponds, respectively, with the first presentation of objects in which the individual is meant to encode the items in the display, followed by a small delay in which only a fixation cross is presented and the participant is meant to maintain the previously presented objects. Finally, a display is presented in which the observer must retrieve from memory and respond whether one of the objects has changed from the first to final object display (Jost et al., 2011). Moreover, individual WMC (the amount of objects maintained) is then determined through the measurement of accuracy based on how many total items were presented in the memory and test arrays (see Scolari, Vogel, & Awh, 2008).

Figure 3

Change Detection Task Example in Jost et al. (2011)



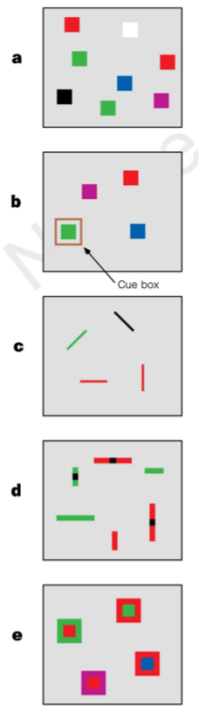
Note. Image adapted from the originally published figure by means of cropping out the relevant panel (A).

In an attempt to investigate memory contents held in WM, researchers have designed experimental paradigms manipulating the content of the objects that individuals are presented with when performing these CDTs. However, as previously mentioned, the findings within this topic have been mixed. Therefore, the focus of the following sections will describe the prevalent studies in this debated topic in terms of their methodology used and their results.

Using changes in color, size and the orientation of bars and squares in a CDT (see Figure 4 below), Luck and Vogel (1997; discussed further in Vogel, Woodman, & Luck, 2001) found that individuals were able to identify when there was a change when only three to four colored objects were presented, however, with an increased number of objects above four, performance decreased. The researchers also found however, that individuals were able to maintain all conjunctions of features consisting of color, size, orientation and whether or not there was a presence of a gap in the object, for the same amount of objects. In summary, individuals could remember four individual features in four objects just as well as 16 features dispersed across four objects (Luck & Vogel, 1997). This finding led the researchers to theorize WM representations to consist of integrated objects as opposed to individuals being limited to storing individual features. These findings would suggest a strong indication of WM as a system limited solely by the number of objects maintained, in that the number of increased features within an object, for example color as well as orientation and size in the case of Luck and Vogel (1997), had no additional, namely detrimental, impact on performance.

Figure 4

Luck and Vogel's (1997) Change Detection Varying Trials



In light of Luck and Vogel's (1997) findings however, Alvarez and Cavanagh (2004) sought to further investigate whether there is a set amount of "visual information" that is maintained within memory representations. In order to conceptualize visual information, the researchers implemented a visual search task in which they measured participant's processing rate of five different stimulus classes consisting of line drawings, random polygons, colored squares, letters and Chinese characters (see Figure 5 below for examples of the stimuli classes and Figure 6 for an indication of the search rate for each stimuli class). The researchers theorized that slower processing rates for a specific stimuli class would equate to more visual information within those given objects. Subsequently implementing a CDT, the researchers found individuals were able to remember more colored squares (defined through the visual information load task as consisting of less information to retain) in comparison to random polygons or Chinese characters (consisting of more information to retain).

Figure 5

Stimuli in Alvarez and Cavanagh's (2004) Study

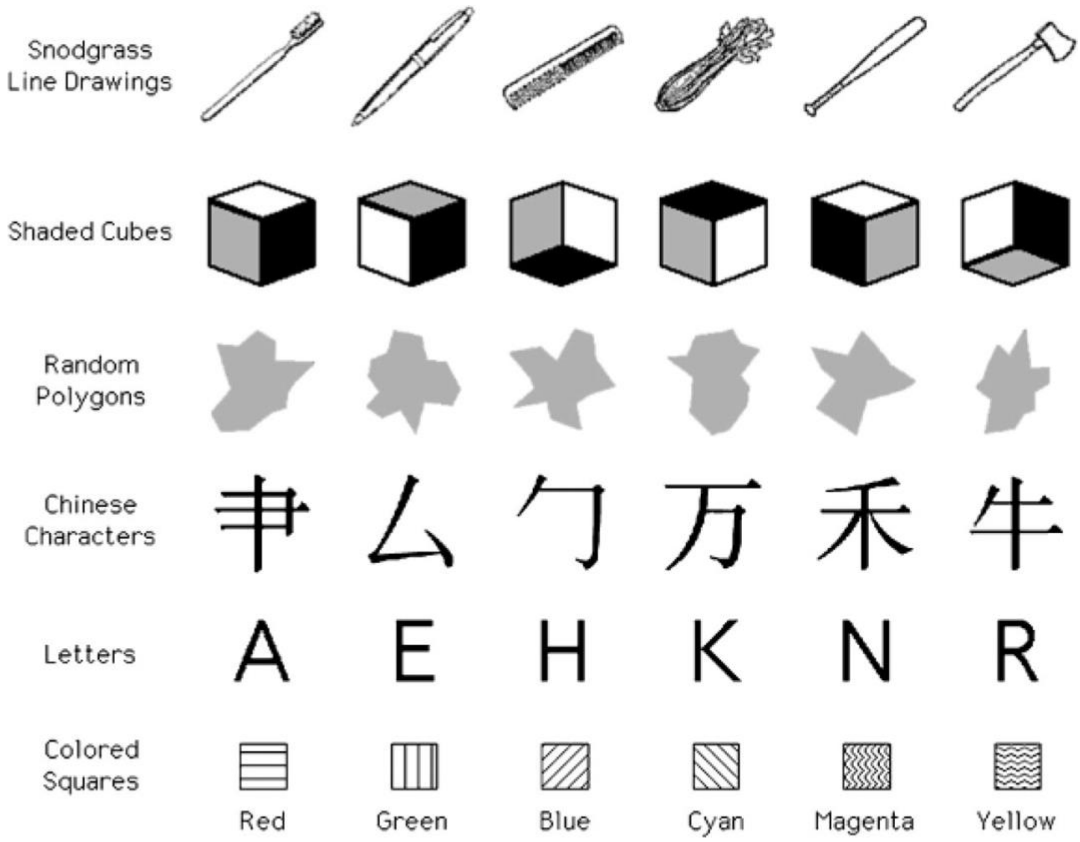
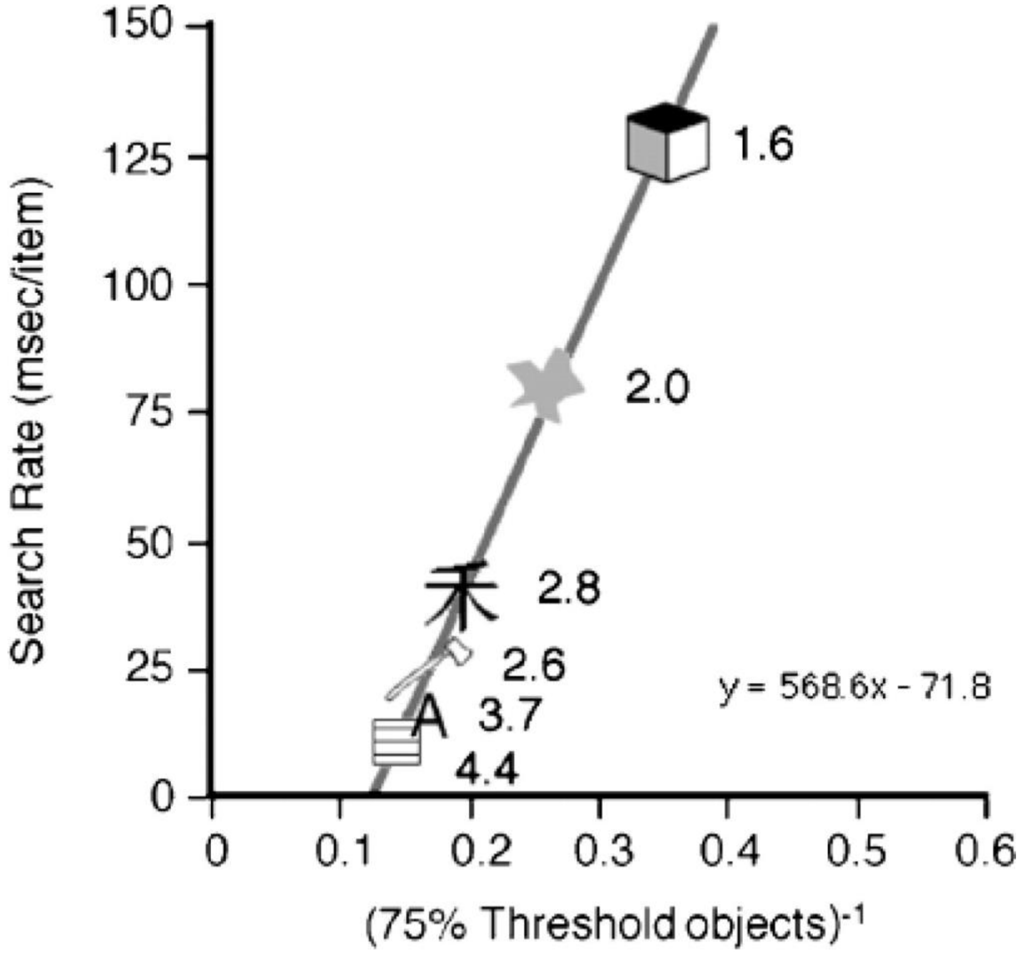


Figure 6

Search Rate of Stimuli Types in Alvarez and Cavanagh's (2004) Study



In opposition to Luck and Vogel's (1997) findings, the results of Alvarez and Cavanagh (2004) suggest that the information load within an object has an impact on how many objects in total can be retained. Important to note though, is that even with lower information loads, WMC in Alvarez and Cavanagh's (2004) study reached a limit of four to five items. The researchers therefore theorize this to suggest both the number of objects as well as information load ultimately have an impact WMC limits. Furthermore, when required to only remember one complex object, for example a shaded 3D cube, participants were not impaired in detecting changes between cubes when only one had been presented, suggesting that participants did not have difficulties in identifying objects with more complex features when individually presented (Alvarez & Cavanagh, 2004). Instead, this suggests that the difficulties that participants demonstrated in displays of more complex objects, and identifying changes within these objects, increased as the amount of objects increased, further implying the content of representations, here conceptualized as information load, to have an impact on how many representations are held in WM (Alvarez & Cavanagh, 2004).

The findings of Alvarez and Cavanagh (2004) may coincide with the low versus high resolution postulation within the flexible resource model of WM (Zhang & Luck, 2008) discussed at the beginning of this section in which individuals maintain several low-resolution representations of colored squares, as the object itself does not require a high resolution. Alternatively, other objects such as random polygons and Chinese characters may require a more high-resolution to maintain in memory, therefore, fewer are subsequently maintained. In light of Alvarez and Cavanagh’s (2004) findings, however, it is also important to consider potential reasons for the discrepancies between these results and Luck and Vogel (1997).

A possible explanation for the differing findings between Luck and Vogel (1997) and Alvarez and Cavanagh (2004) may lie in the differing type of stimuli used to investigate the same overall concept: the content of representations held in WM and whether these representations then have an impact on how many objects are maintained. More specifically, it is possible that the stimuli classes used in Alvarez and Cavanagh (2004), varying from line drawings, random polygons, colored squares, letters and Chinese characters, are arguably more complex than abstract squares and bars differing only in rudimentary or geometrical features such as color or orientation as used in Luck and Vogel (1997).

In line with this, Awh, Barton, and Vogel (2007) sought to extend Alvarez and Cavanagh's (2004) findings, using the same stimuli set, however also investigating whether potential comparison errors occurring within the retrieval stage had an impact on performance. To do so, the researchers implemented conditions with objects that had been determined to be more complex, and then manipulated the similarity between the sample and test array presentations with the aim to investigate whether performances would then be similar to conditions with simple objects. For example, the researchers included trials in which a Chinese character (determined to be a complex object), presented among other objects, would change to another, different, Chinese character. In alternative trials, the Chinese character would instead change to a completely different object, such as a cube. The researchers found that participants were able to detect these larger changes from Chinese character to a cube, however, participants had difficulties in identifying when there was a change from a complex object to another complex object. However, similar to Alvarez and Cavanagh (2004), participants did not demonstrate difficulties in identifying changes in complex objects when only one complex object was individually presented, for example a cube changing to another cube. Awh et al. (2007) take their findings to suggest that less information, or a lower-resolution of individual objects are stored when there are more objects to be stored. Moreover, with increased similarity between object displays, for example when a complex object changes to another similar object, performance is limited by the individual's comparison of the two objects. However, Awh et al. (2007) additionally theorize that when objects are conceptualized as being less difficult, potentially as in the case of the colored bars in Luck and Vogel (1997), performance is limited solely by the individual's fixed capacity limits.

Accordingly, the findings of Awh et al. (2007) suggest important considerations for WM representations in that capacity appears to be fixed to a certain level, about three to four objects, regardless of the object content. However, object content also appears to have an impact on the resolution of the items maintained. Additionally, performance can be aided by low similarity between memory and test array objects in that participants, even with low-resolution representations held in WM can identify whether there has been a change in the test display. Alternatively, the findings of Awh et al. (2007) also suggest that performance can be hindered when there is a high-similarity between the objects presented in the memory and test array, as the original object display was potentially encoded with low-resolution.

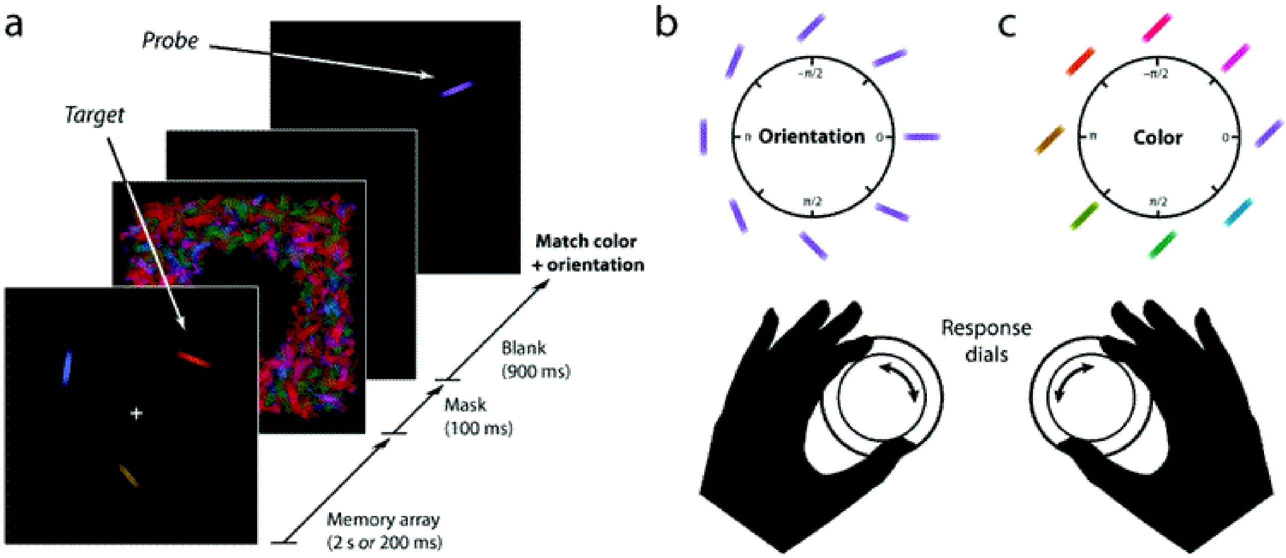
The manipulation of item similarity has been used more recently in vWM research. This examination investigates the influence of high and low similarity amongst items across a memory display on the influence of performances when the recall of one of the items is required (Brady & Alvarez, 2011; Hu & Jacobs, 2021; Lin & Luck, 2009; Markov, Utochkin, & Brady, 2021). For example, Hu and Jacobs (2021) conducted four experiments in which they manipulated the category relationship between items presented in a memory array either to belong to the same group (coherent) or not (incoherent) and found improvements in vWM performances in coherent trials. Lin and Luck (2009) also found similar results utilizing a CDT with colored dots either similar or not similar to the other dots in the display. Similarity however is not only limited to low-level features such as color and shape. Similarity effects have also been observed in real-world object searches with categorical similarity as the manipulation (Alexander & Zelinsky, 2011; Schmidt & Zelinsky, 2009). Utilizing eye-tracking measurements, Alexander and Zelinsky (2011) found, when a target was not present, eye movements were also directed initially towards distractor objects that were similar visually to the target object category as well as the inverse effect of eye movements that were directed away from dissimilar target objects. Evidently, when shifting to more realistic objects as stimuli in visual displays, additional characteristics including category similarity should be considered. With that being said, it is of importance to recognize that lower-level features, such as color, shape and orientation, and higher-level features, such as category, are not entirely disparate (see Zelinsky, 2003). Accordingly, to manipulate only higher-level features, without considering the influence of the lower-level features, is fruitless. The influence of the manipulations of both types of features in their similarity relationship to other objects in visual displays is investigated further in this thesis.

Working Memory Representations in Older Adults

Although the research that has been done in the topic of age-related precision of WM representations has been limited, there has been some research conducted in this area investigating OA's precision of WM representations. Peich et al. (2013) implemented a task in which participants were shown displays of colored bars set to different orientations (see Figure 7 below for an example). When participants were presented with a probe during the test array, they were then asked to adjust two dials (one corresponding to color and the other corresponding to orientation) to the bar(s) that had previously been presented in the memory array in the same spatial location as the probe item.

Figure 7

Dual Feature Task Procedure Example from Peich et al. (2013)



Note. "Reproduced with permission from American Psychological Association. No further reproduction or distribution is permitted."

The researchers found OAs to be significantly impaired in reporting both the precision of the color and orientation of the bars, even in memory loads of only one item to maintain, but even more so as the memory load of objects presented increased (up to three bars presented at once). These findings led Peich et al. (2013) to suggest that the precision, or resolution, of WM representations decline in aging. Overall, these findings suggest OAs to demonstrate impairments in the precision of WM representations, with impairments being even more prominent with increasing amount of items to maintain.

As discussed, it is important to characterize the precision of OA's WM representations. It is possible that OAs maintain in memory the same amount of objects as YAs, however, just with a lower precision (this would coincide with Peich et al., 2013, in which OAs were impaired even in condition with one item). Furthermore, additional researchers explored this issue of precision and vWM representational decline in aging (Mitchell, Cam-C.A.N., & Cusack, 2018; Mok, Myers, Wallis, & Nobre, 2016; Pertzov, Heider, Liang & Husain, 2015), each finding similar results as Peich et al. (2013). Moreover, also akin to Peich et al. (2013), these studies explored the issue of precision of WM representations in aging through the use of geometrical stimuli: oriented colored lines or fractals. Clearly, while there is a shift in the right direction in the aging and vWM field to not solely considering the quantity of OA's memory decline, real-world objects are not typically the manipulation.

Concluding Remarks

As previously mentioned, WM abilities typically decline with age. However, the specifics of age-related WM degradation are not well investigated. Declines that are specific to the content of the representations that OAs are able to maintain in WM has been under investigated in this age group. Specifically, it is known that OAs have lower performances on CDTs (Ko et al., 2014; Sander et al., 2011), as well as in some cases differing electrophysiological responses (Jost et al., 2011; Schwarzkopp, Mayr & Jost 2016; Störmer, Li, Heekeren, & Lindenberger, 2013), however, research findings are unclear as to whether the contents of the representation OAs are able to retain may solely account for reported age-related differences in capacity. Moving towards a more comprehensive understanding of WM abilities and declines in these abilities for OAs has the potential to provide a more general understanding of cognitive decline in aging, given the discussed associations of WM with other cognitive abilities.

Previous investigations in the more general question of WM as a fixed capacity or as a flexible resource have been met with varied results. Although there has been very little research conducted in OAs regarding the precision of WM representations, the little research that has been done has suggested the possibility that there are age-related differences in WM not only related to a lower capacity, but also related to the nature of the representations (Mitchell et al., 2018; Mok, et al., 2016; Peich et al., 2013; Pertzov et al., 2015). Additionally, of utmost importance, these studies have predominately relied on geometrical stimuli as opposed to using real-world objects, an important manipulation that future research should consider (Asp et al., 2021; Brady et al., 2016).

1.2 Aging and Attention Measured Through Visual Search Tasks

Age-Related Decline in Attention

As discussed prior, OAs commonly demonstrate deficits in attention (Madden & Langley, 2003). Importantly, a decrease in resources of attention are also theorized to underlie age-related WM impairments (Naveh-Benjamin & Cowan, 2023). Moreover, attention is incredibly pertinent not only to cognitive functions such as WM, but also in determining OA's performances throughout other cognitive paradigms (see Madden & Langley, 2003). Accordingly, age-related declines in attention are not only prevalent, but also expand to other domains, such as WM. Investigating the specifics of age effects in attention are evidently imperative.

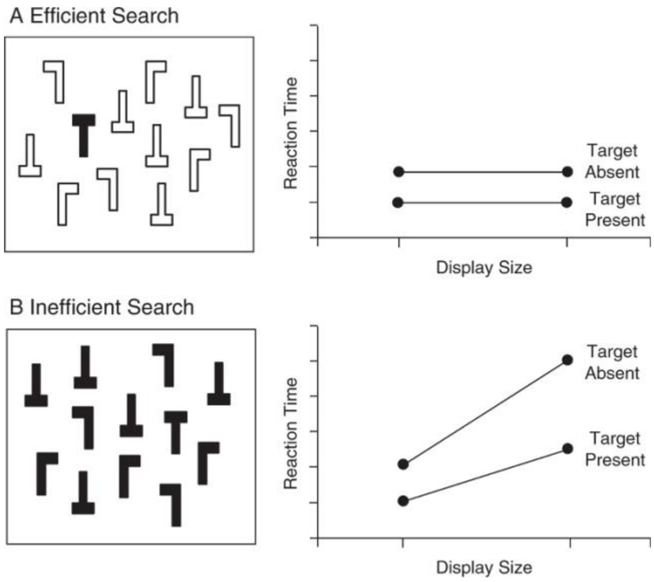
Importantly, not all attention functions have been found to be impaired in aging. Certain attention functions including top-down attentional control (Madden, Whiting, Cabeza, & Huettel, 2004) or the qualitative efficiency of search (Wiegand & Wolfe, 2020) as well as focused attention (Souza et al. 2023), have been found to be intact in aging. Clearly, developing a better understanding of which attention abilities are impaired, or in turn preserved, throughout the discourse of aging is important.

Attention and Visual Search

As mentioned prior, a useful method to measure attention functions are Visual Search Tasks (VST), in which the subject must search for either the presence or absence of a target presented along with other distracting items (Wolfe, 1994). In VSTs, the main measurement of interest is typically the reaction times (RTs) as a function of the overall number of items, also known as the "set size" (Wolfe & Horowitz, 2004). Typically, these RT x set size "slopes" are flat when the target "pops out" in the display, in that the increase in items does not lead to slower performances (Plude & Doussard-Roosevelt, 1989). A "pop out" in a display is an item that is distinguishable by at least one feature amongst the other items in the display (Plude & Doussard-Roosevelt, 1989). An example of this would be the black letter "T" in Figure 8 ("Efficient Search"; Madden, 2007).

Figure 8

Visual Search Task Condition Examples from Madden (2007)



Alternatively, when search is more difficult (for example when a target item is less noticeably distinguishable from the others: see "Inefficient Search" in Figure *8*), slopes typically become steeper, in that with a higher amount of objects in the display, RTs in turn become longer (Wolfe & Horowitz, 2004).

Two main types of search have been the hallmark manipulation in early VST research: feature and conjunction search. A feature search condition would be analogous to the previously presented condition in Figure *8* ("Efficient Search") in which a target is distinguishable from the others, due to a discernible feature (Madden, 2007). Importantly, the set size of the items in the display is theorized to be irrelevant for the identification of this type of target (Harpur, 1991). In contrast, a conjunction search condition is a type of search when a target (comprised of a conjunction of features) shares one or more of those features with the distractor items also in the display, in turn making the search more difficult ("Inefficient Search" in Figure *8*, Madden, 2007).

These types of search, and their underlying processes involved, are explained under the framework of Feature Integration Theory (FIT; Treisman, & Gelade, 1980; Treisman, 1982). The FIT proposes a two-process model in which first, features are registered "pre-attentively" and parallelly (Treisman, & Gelade, 1980; Treisman, 1982). Secondly, through the employment of focused attention, features are then integrated together (also can be considered as "bound") in order to represent an object (Treisman, & Gelade, 1980; Treisman, 1982). Wolfe (2021) explains the enaction of this attention mechanism to be limited in capacity and that each item is considered individually.

Naturally, conjunction search is more difficult and with increased display items, leads to steeper RT slope performances (Scialfa, Esau, & Joffe, 1998). Proceeding theories have been developed to further explain the two-stage processing of FIT, including an alternative model based on conjunction search in which each feature is independently processed, and every item in the search display is assessed against the target (Treisman & Sato, 1990). The general idea is similar however: an individual demonstrates steeper slopes when there are more shared features between target and distractor items. Under the idea of FIT, Plude & Doussard-Roosevelt (1989) describes, distractor items impede the recognition of the target when features are comparable between target and distractors. Alternatively, when the target does not contain comparable features with distractor items, only the first parallel stage is necessitated to identify the target (Plude & Doussard-Roosevelt, 1989). Moreover, the less shared features between target and distractors, the display size typically does not have a resultant impact on RTs (Harpur, 1991; see Wolfe, 2021 for a review).

Additionally, the Guided Search model, which was first developed in 1989 (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989) and the most recent model being developed in 2021 (Guided Search 6.0; Wolfe, 2021), has been equally as influential in the visual search field. At the core of the initial Guided Search (GS), is the idea that pre-attentively registered features could be used to "guide" attention. Wolfe (2021) explains that overall the FIT and the GS are quite similar, with the important difference being that while in the FIT the two-stages of feature and conjunction assessment are separate, the GS instead theorizes a "*continuum based on the effectiveness of guidance*" (Wolfe, 2021, p. 1062). Importantly, the GS model proposes that when similarity between target and distractors increase (ie., less distinguishability between target and distractors), parallel search becomes less efficient, shifting then to serial search (Wolfe, 1994).

Additional models, including the Theory of Visual Selection (Duncan & Humphries, 1989), also discuss the decrease in search efficiency when there are less distinguishable targets from distractor items, as well theorizing this process to be "resource-limited" (Scialfa & Thomas, 1994). Scialfa and Thomas (1994) discuss the agreement across the different visual search models when it comes to similarity between targets and distractor items, as well as the influence of the amount of items, in that the comparison process that occurs between distractors (possible targets) and an internal target representation, is resultantly longer when there is a higher similarity between items, as each item needs to be assessed before being "rejected" as not being the target item.

Evidently, across each of the models, the influence of an increasingly similar relation between target and distractors is important in determining performances (see also Wolfe & Horowitz, 2004 for a discussion), as well as in determining the impact of increased display size effects (Harpur, 1991; Scialfa & Thomas, 1994). These effects, while prevalent in YAs, are known to be exacerbated in OAs. As such, these studies and their findings (predominately using geometrical stimuli) will be discussed below.

It is important to also consider a line of research using complex stimuli such as line drawings (Belke, Humphreys, Watson, Meyer, & Telling, 2008; Loftus & Mackworth, 1978) and real-world objects that have suggested an alternative theory to that of low-level features as guiding visual attention. Utilizing eye-tracking measurements and presenting real-world objects, Cimminella, Sala and Coco (2020) and Nuthmann, De Groot, Huettig and Olivers (2019) have suggested the semantic content of objects are visually processed extra-foveal and guide early attention. The importance of the findings of these studies is two-fold. First, this research suggests not only low-level features may guide early attention in visual search, but also contextual information may guide early attention as well when using realistic objects or scenes as stimuli in a visual display. Moreover, this research also highlights the importance of eye-tracking for measuring attention. Both of these points will be discussed further below.

Attention, Aging and Visual Search

Extensively, seminal aging studies found similar search abilities between older and YAs in feature search, with evident and exacerbated age-effects found in conjunction search. Madden (2007) terming feature search as "Efficient Search" (Figure *8*) found very similarly flat search slopes between OA and YA in a feature condition. Alternatively, in "Inefficient Search" conditions, namely when there was an increased amount of similarity between target and distractor items (Figure *8*), OAs produced steeper slopes relative to YAs (Madden, 2007).

This finding has been demonstrated across a plethora of aging studies using geometrical stimuli. For example, Plude and Doussard-Roosevelt (1989) had the aim of investigating the precipitators of OA's selective attention impairments in VSTs and presented OAs and YAs with "feature extraction conditions" (feature search) and "feature integration conditions" (conjunction search) as well as a third "unconfounded conjunction search", examining possible qualitative search differences. The unconfounded condition was a manipulation allowing the researchers to investigate the parallel processing occurring in conjunction search (Plude & Doussard-Roosevelt, 1989). In search displays including 5, 15 and 25 items with two color possibilities (red or green) and two "form" possibilities: O or

X’s: therefore, there were four item possibilities of the items: red O’s, red X’s, green O’s and green X’s. This led to conditions of three display set size conditions (5, 15 and 25), four item display types (feature, conjunction and unconfounded in relation to the target) and conditions in which the target was present in the display or absent (Plude & Doussard-Roosevelt, 1989). The researchers found that “negative probe” conditions (no target present) led to longer reaction times (RT) than “positive probe” (target present) conditions, as well as the higher display size conditions, and both effects were exacerbated in OAs. Importantly, of the three display condition types (feature, conjunction and unconfounded), the degree of the age differences found were the strongest in the conjunction type search conditions (Plude & Doussard-Roosevelt, 1989). This suggested to Plude and Doussard-Roosevelt (1989) that the feature extraction stage is intact in aging, whilst age-related impairments arise in the conjunction stage, also with OAs demonstrating exacerbated influences of the higher set sizes (Treisman, & Gelade, 1980; Treisman, 1982). The researcher’s implementation of the unconfounded condition found search behaviors in this condition to be similar between OAs and YAs, and accordingly led the researchers to conclude that the age-effects found in their study, namely those found from the conjunction search condition, to be quantitative rather than qualitative (Plude & Doussard-Roosevelt, 1989).

Further investigating selective attention abilities across aging, Foster, Behrmann, & Stuss (1995) implemented a VST under the framework of the FIT (Treisman, & Gelade, 1980; Treisman, 1982). The researcher’s main questions, aside from age effects in these different types of searches, concerned whether Plude & Doussard-Roosevelt's (1989) findings of age-effects in conjunction search would be replicated across other dimensions, including shape and stimulus shading (Foster et al., 1995). For their study, the researchers used one constant target, in which the identification of this target was based on whether a feature (shading) was either present in the stimulus target or absent on a trial (Foster et al., 1995). Akin to Plude and

Doussard-Roosevelt (1989), Foster et al. (1995) also implemented an unconfounded condition, allowing them to also look at possible qualitative differences in search in aging. For this manipulation, the researchers kept the amount of distractors fixed, varying the amount of feature changes (shape or shading) across trials within this condition. The researcher's question was whether OAs could efficiently use the information qualitatively across the different trials for more efficient search. In line with Plude and Doussard-Roosevelt (1989), Foster et al. (1995) found intact age-related performances in the feature search conditions, with age-effects arising during the conjunction search conditions. Concerning the unconfounded condition, the researchers found no qualitative difference between the age groups in this condition, also akin to the findings of Plude and Doussard-Roosevelt (1989). This suggested to the researchers that visual search behaviors between the two groups is slower in OAs overall, but qualitatively similar across the discourse of aging.

Scialfa et al. (1998) also added to the aging and VS field by implementing a task with feature and conjunction search conditions containing 2, 4 or 8 items with varying levels of similarity. For their study, a high level of similarity was signified through line degree differences within a circle between a target as a vertical line presented and distractors as lines oriented 30 degrees from vertical, also presented within a circle. Alternatively, a low level of similarity was a circle with a vertical line as a target presented amongst distractors which were horizontal lines presented within circles (Scialfa et al., 1998). The researchers found OAs demonstrated impairments in the conjunction search conditions, higher display size conditions, as well as in the higher similarity manipulation conditions and in target absent conditions. Harpur (1991) using similar manipulations of target circles with either a horizontal or vertical line inside, and distractor circles with lines of varying degrees, similar or dissimilar to the target, found similar results.

Researchers Scialfa and Thomas (1994) wanted to explore the precursors to these age effects in visual search conditions of increased similarity (namely, conjunction searches). As discussed prior, one of the leading theories of enhanced effects when there are more items in the display are due to the time required to compare the internal target representation and each similar distractor (Scialfa & Thomas, 1994). The researchers discuss that to conclude solely based on seminal aging and visual search studies that OA's difficulties are due to a slowing of this comparison in particular, would be "premature" due to the multitude of other factors involved during these searches (eye movements and working memory capacity, for example). To circumvent these issues, Scialfa and Thomas (1994) implemented a task, initially designed by Nickerson (1965), in which OAs and YAs had to determine whether two objects were the "same" or "different" as the other. The two objects presented could be the same or have differential features (including shape, color or their size). The researchers used eight objects that varied in the dimensions of size: large or small; shape: a circle or a square and color: green or red. Half of the experiment trials had the exact objects presented, while the other half of the trials had objects that differed in one, two or three of the dimensions (resulting in varying degrees of similarity in each of the features). Scialfa and Thomas (1994) found that OAs had disproportionately longer RTs on trials that were "different" and additionally in which the pairings were more similar. The researchers argue that their findings suggest age-related differences with increased similarity in objects align with impairments in the comparison process of objects.

Accordingly, important to consider is whether age-effects in search are only found when there is increased similarity between targets and distractor items. Recent research on age-effects in a form of visual and memory search ("hybrid search") suggest minimal age effects (Wiegand & Wolfe, 2020). Exploring possible age differences in hybrid search using real-world objects (a search in which both the amount of targets and distractors are manipulated), Wiegand and Wolfe (2020) implemented three different experiments, first assessing hybrid search in aging, finding no age-effect (aside from RT increases with higher amount of items in the visual search display). The researchers then also implemented follow-up experiments; first to see whether the OAs in their study utilized a technique in order to pick out their target, based on their familiarity with the real-world images. Finally, implementing an additional manipulation of target-context associations in relation to the visual search background, the researchers again found no disproportionate age effects. In each of the three experiments, while the researchers found that OAs demonstrated a slowing of RTs overall, once RTs were statistically standardized, the disproportionate age effect disappeared. This suggested to the researchers a quantitative difference (slower RTs) across aging in search abilities, but not a qualitative difference in OA's search abilities. Why did Wiegand and Wolfe (2020) find different results than the aforementioned earlier studies (Plude & Doussard-Roosevelt, 1989; Scialfa & Thomas, 1994; Scialfa, Esau, & Joffe, 1998)? A possible explanation was provided by Wiegand and Wolfe (2020) in which the researchers suggested that the use of real-world objects in their study allowed both age groups to develop more robust "representations" of the images. Also, importantly, the researchers did not manipulate the association between target(s) and distractor(s). Possibly, this lack of similarity between target and distractors was crucial in eliminating age differences in this search task (Wiegand & Wolfe, 2020).

Overall, it is difficult to tell if age impairments are due to an increased amount of features to recall (as measured by conjunction searches), or instead are due to a decline in the content of the representation. Akin to the majority of WM studies discussed above, the majority of studies implementing VSTs with OAs (with the exception of some more recent studies: Wiegand & Wolfe, 2020), have relied on the use of geometrical stimuli (Plude & Doussard-Roosevelt, 1989; Scialfa & Thomas, 1994; Scialfa et al., 1998). These studies have ultimately been informative in suggesting disproportionate age effects of the similarity between objects in the display, exacerbated when there are more items. However, how do these similarity effects specifically expand (or not) when real-world objects are the stimuli implemented?

With the aim of investigating age-related performances in visual search using real-world objects while also implementing eye-tracking measures, Williams, Zacks, & Henderson (2009) manipulated different search arrays with 12 objects to include 0-3 targets in the search array. The interesting manipulation in this experiment was that the distractor objects in the display were matched to the target in either color (3-4 distractors), category (3-4 additional distractors), or were completely unrelated to the targets (3-4 more distractors). "Category" in their study was a distractor that was the same type of object as the target (for example, if the target was a yellow drill, a category distractor would have been a red drill) Williams et al., 2009). When it came to strictly the visual search results, the researchers found OAs were less accurate and slower than YAs and this negatively interacted with an increased amount of target items as well. However, the visual search analyses cannot independently measure whether categorically or perceptually similar distractors disproportionately impacted OAs in comparison to YAs, as the display always included 3-4 of each of these types of distractors. Nonetheless, the researchers did find interesting age-related results concerning their eye-tracking measurements. OAs disproportionately viewed for longer the target items and then the category distractors, followed by the color distractors and lastly the unrelated distractor objects. Younger adults in comparison viewed the target objects earlier in the display presentation than OAs, however, considering the duration of fixating on targets, OAs disproportionately fixated on these target items for longer. Additionally, the researchers found that OAs viewed more unrelated distractors as well as the category distractors than YAs did, and additionally viewed these distractors earlier on in the trial. Alternatively, concerning the proportion of views, YAs viewed a higher proportion of color distractors, than OAs (Williams et al., 2009). Evidently, these results suggest age-differences in the way in which real-world objects are assessed, dependent on the type of characteristics of the objects.

As mentioned previously, more recent research has focused on using more realistic stimuli, including real-world objects (Asp et al., 2021; Brady et al., 2016). In using real-world objects for experimental manipulations, one should acknowledge that real-world objects are comprised of a multitude of visual and semantic features that can augment how they are represented. Williams et al. (2009) suggests an important consideration of the features comprising real-world objects, namely the perceptual and conceptual nature of the object. Perceptual feature for the sake of Williams et al. (2009), as well as in the current thesis, is color, although it is important to note perceptual features can be conceptualized through other features as well, for example shape. An additionally important feature to consider is the conceptual nature of the object, which can be considered as the semantic category in which the object could belong. The consideration of manipulating in particular these different featural considerations (perceptual and conceptual) is two-fold. First, the recent shift in using more realistic stimuli such as real-world objects and contextual scenes (see Belke et al., 2008; Cimminella et al., 2022, 2020; Nuthmann et al., 2019) have suggested the importance of considering the categorical characterization of images in determining behaviors. Interestingly, recent research has found perceptual features of real-world objects to impact vWM storage to a greater degree in young adults, compared to conceptual features (Li, Chen, Sun & Li, 2023). With that being said, the two features are intrinsically linked (see Zelinsky, 2003). Therefore, akin to Williams et al. (2009), the current thesis will examine both features further.

Secondly, the manipulation of these two features is also an interesting consideration in aging. This importance follows from previous findings of intact semantic abilities and representations in OAs (Burke & Peters, 1987; Naspi, Stensholt, Karlsson, Monge, & Cabeza, 2022), with visual perceptual abilities believed to decline in aging (Monge & Madden, 2016;

Owsley, 2011). For example, OAs are known to have a high level of semantic association abilities, due to a high vocabulary level (Burke & Peters, 1987) and intact semantic picture association abilities, which has been suggested to compensate for declining memory in aging (see Cherry et al., 2012). Furthermore, the information degradation hypothesis suggests impaired perceptual "signal inputs" that are due either to experiment manipulations or neurobiological processes in aging, precipitate perceptual processing impairments, then impacting cognitive abilities (Monge & Madden, 2016). There has also been a field of aging research probing the false recognition of new stimuli based on an increased reliance on either conceptual and perceptual features of previously presented stimuli (see Pidgeon & Morcom, 2014). Further evidence reinstating the differential representation of these two features has been demonstrated by a recent functional magnetic resonance imaging (fMRI) study that found less differentiation in OAs in the early visual cortex when processing sensory features, as well as a hyperdifferentiation in aging of category features in the anterior temporal lobe (Deng et al., 2021). Evidently, not only is it important when shifting towards the use of more realistic objects, or scene contexts, to consider both categorical and perceptual features, but additionally, there are suggestions that these two features may also be differently impacted, and represented, in aging. Accordingly, this is a topic that the current thesis will investigate further.

Interestingly, additional studies that have implemented real-world objects in their experiments, also along with eye-tracking, have found intriguing age-related differences in the manner in which objects are assessed, including a reliance (sometimes to a detriment) in aging when looking at real-word scenes, and expecting a target to be in the most semantically-consistent location (i.e., looking for a target kettle on the stove, as opposed to the kitchen floor: Wynn, Ryan, & Moscovitch, 2019; Borges, Fernandes, & Coco, 2020; Ramzaoui et al., 2022; although see Ramzaoui, Faure, & Spotorno, 2021 and Rehrig et al., 2022). Early research in aging using eye-tracking and implementing geometrical stimuli suggest OAs may be more prone to viewing distractors, particularly when the distractor had the same type of contrast (either white or black) with the target (Dennis, Scialfa, & Ho, 2004). Evidently, there appears to be an exacerbated age effect when a conjunction of features need to be successfully retained. There also appears to be age differences in the manner in which features are viewed and prioritized. Accordingly, the assessment of ocular movements is useful in developing a more comprehensive understanding of guided attention as well. Measuring ocular movements allows for the investigation of possible age-related differences in the assessment of real-world objects, due to the richness and precision of eye movement data in indicating how and which objects are assessed, that expand beyond that which can be measured through reaction times and accuracy analyses. Eye movement recordings have also been suggested to be important in the assessment of cognitive decline in aging (Ionescu et al., 2023), reinforcing the importance of implementing such measures. This is a topic that the current thesis will (partially) address.

Concluding Remarks

Seminal aging and visual search studies have demonstrated a specific age difference in conjunction search (Harpur, 1991; Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998). These effects appear to be exacerbated even further when there are more items in the display (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998). More recent research using real-world objects as stimuli in visual search and aging, has suggested OAs do not have an enhanced effect of more items, once age-related slowing performances are standardized (Wiegand & Wolfe, 2020). However, this research did not manipulate the similarity amongst the objects in the display, leaving the question whether the earlier studies in visual search and aging using geometrical stimuli that found an influence of the similarity between target and distractors, would lead to effects also when real-world objects are used. Williams et al. (2009) approached this question, however importantly, only manipulated real-world objects in one type of similarity feature individually of 3-4 distractors each, including other similarity manipulations of distractors also in the display as well. Possibly the smaller amount of similar distractors, and the presence of other types of distractors was not enough to influence OA's visual search behaviors. Additionally, Williams et al. (2009) did not manipulate set size in their study (always presenting 12 total objects), and this is arguably an important manipulation in investigating the quality or quantity influence of OA's possibly intact or preserved visual search abilities. The results of Williams et al. (2009) do however suggest an important consideration when investigating visual search and aging, namely, the manner in which objects are assessed, including the amount of time assessing the objects, and viewing different types of objects more (category and unrelated distractors). The results of Williams et al. (2009) as well as others (Borges et al., 2020; Ramzaoui et al., 2022; Wynn et al., 2019) suggest important age differences in the manner in which objects are assessed dependent on the characteristics of the features. Evidently, including eye-tracking measures are important in determining age differences in visual search.

1.3 Thesis Project Aims

The aim of this thesis project was to explore the influence of the nature of object representations, either in the interaction with object numerosity (**Chapter 2-4**), or alone (**Chapter 5**), on cognitive aging. The secondary aim of this thesis project was to study this using real-world objects, given their higher applicability to everyday life.

The majority of the previously described studies in aging have relied on geometrical shapes, as discussed above. However, geometrical shapes lack several features that are in contrast contained in the real world (i.e. when real-world objects are used). Thus, it is important to understand OA's representations of these types of items. For instance, recent evidence has indicated that young adults have enhanced performance in detecting real-world stimuli (Brady et al., 2016) as well as higher working memory capacity (WMC) for stimuli that are discerned as "meaningful" in comparison to ambiguous stimuli (Asp et al., 2021). Therefore, investigations measuring the content of WM representations in OAs as well as attentive abilities may benefit from using real-world stimuli. Moreover, manipulating the conceptual and perceptual features of real-world objects was chosen first, given the involvement of the two of these features in comprising real-world objects (see Zelinsly, 2003 and discussion above), as well as previous aging research finding semantic knowledge to be intact in aging (Burke & Peters, 1987), and visual perceptual abilities to decline (Owsley, 2011). Moreover, given recent fMRI evidence that has further suggested a dedifferentiation of perceptual features in aging, as well as a hyperdifferentiation of conceptual features (Deng et al., 2021), this additionally suggests the manipulation of these two features to be interesting to consider further in aging research.

Furthermore, although there has been research conducted investigating age-related differences in the differential representation of conceptual or perceptual features, little research has been conducted investigating whether an increased similarity between real-world objects in these two features precipitate age-related impairments. Moreover, an additional under-addressed question concerns whether these features possibly influence age-related performances in conjunction with the amount of objects presented, in tasks in which OAs are known to demonstrate impairments. Essentially, does the content of object representations (measured by proxy of conceptual and perceptual similarity manipulations), have an additional effect in aging, or is only the numerosity of objects important in determining age impairments?

More specifically, the main objectives of this thesis were to investigate in aging the interaction between object representation and object numerosity in the domain of vWM and attention. The focus on memory was due to the plethora of research indicating declined vWM abilities in aging (Jost et al., 2011; Ko et al., 2014). Moreover, due to a vast amount of research in aging finding OAs to have more difficulties when attention is required (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998), the second main aim was to investigate in aging the ability to allocate attention to select a real-world target object from a display. This investigation was examined through two different measures: 1) manual responses in a VST and, 2) measuring oculomotor behavior in directing vision towards a pre-defined real-world object.

In order to achieve the first aim, in Chapter 2 I present a mini-review in which I discuss research in aging that has been conducted investigating the influence of the nature of object representations through means of feature binding. I then propose in the mini-review that future research in aging should implement investigations considering both feature binding in conjunction with numerosity manipulations. These manipulations of both object content and numerosity will provide insight into the mechanisms at play in aging in determining performances.

Next, in Chapter 3 in two different experiments, I manipulate within CDTs, first the conceptual, and then the perceptual nature (both with the crucial manipulation of set size as well) amongst the real-world objects presented to older and young subjects in a display and measure subjects' individual item recall. Here, the main question being addressed is whether OAs perform differently than young adults when the objects presented that need to be retained and recalled vary in conceptual or perceptual similarity with respect to the other items.

Secondly, in Chapter 4, in two different experiments (one first with a smaller range of set sizes: 5, 7 and 10 objects and then with a larger amount: 10, 12 and 15 objects), it was explored how aging influences visual attention as a function of distractor numerosity and the similarity between target and distractor; in terms of perceptual compared to conceptual features. Accordingly, I manipulated the entire display to be either entirely perceptually similar or entirely conceptually similar, across different trials, allowing me to isolate the question of whether age-related performances in visual search are separately influenced by either perceptual or conceptual similarity.

Finally, in Chapter 5, I further investigated age-related effects on attention search by assessing oculomotor behavior. The implementation of oculomotor measurements was to utilize a more sensitive measurement, compared to strictly behavioral measures and responses, in order to examine possible age-differences in the influence of the nature of object representations in capturing attention. Therefore, in this study, I sought to track eye movements in OAs and accordingly examine the trajectory of eye movements when presented with a predefined target item and a distractor item, either similar in perceptual (two levels) or conceptual (two levels) features. Moreover, differently from Chapter 4, in Chapter 5, I also implemented two levels (i.e. precisely the same featural similarity versus similar featural similarity) of conceptual and perceptual similarity, allowing me to look at these two features more closely.

Chapter 2

Aging and feature binding in visual working memory

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Abstract

Older adults have reduced performance in visual working memory tasks in comparison to young adults, but the precipitators of the age-related impairment are not fully understood. The most common interpretation of this difference is that older adults are incapable of maintaining the same amount of object representations as young adults over short intervals (in line with the fixed-slot model of working memory). However, it has remained largely unexplored whether the age-related decline is only due to the number of representations that older individuals can retain in visual working memory, or whether the content of the representation(s) may have an effect as well (in line with the flexible-resource model of working memory). Feature binding studies represent an interesting research line to examine the content of older adults' representations. In this mini-review, we present the main results across feature binding studies in aging, as well as highlight the importance of manipulating both the representation content and number to have a stress test of the various models of working memory and their contribution to aging. Overall, feature binding studies, together with the simultaneous manipulation of set size, will allow us to better understand the nature of the age-related decline of visual working memory.

Keywords: feature-binding, visual working memory, cognitive aging, object representations, set-size

Introduction

A typical cognitive impairment that follows the discourse of aging is reduced performance in working memory (WM) tasks (Salthouse et al., 1991; Park et al., 2002). This is generally observed as a lower accuracy in older adults (OAs) compared to young adults (YAs) with increasing sets of objects that need to be remembered (Jost et al., 2011; Sander et al., 2011; Tagliabue et al., 2019; Tagliabue et al., 2022). Because of the set size manipulation, most studies have concluded that there is a reduction in the amount of object representations that OAs can hold in WM in comparison to YAs (Jost et al., 2011; Schwarzkopp et al., 2016; Tagliabue et al., 2020 but see Oberauer & Kliegl, 2010); this interpretation falls in line with the viewpoint of WM capacity as a fixed-slot model (Luck & Vogel, 1997; Cowan, 2001; see Adam et al., 2017 for more recent results), in which an individual's WM is set at a fixed number of representations, regardless of the content of the representations (Awh et al., 2007).

The fixed-slot model has been extensively researched in YAs, however met with inconsistent conclusions (see Alvarez and Cavanagh, 2004; Awh et al., 2007). An alternative viewpoint described WM in terms of functioning "flexibly," in which limits vary as a function of the content of the object representation to maintain, and also at the detriment of less precise representations with increased amount of items to retain (Wilken and Ma, 2004; Bays and Husain, 2008). The issue of whether the nature of the representations (rather than their number) could be a key factor in understanding WM, is still under investigation in healthy young individuals (see Adam, et al. 2017; Adam and Serences, 2019; Bouchacourt and Buschman, 2019), and has received little attention in the field of aging research. Specifically, the question remains as to what leads OAs to impaired performance in WM tasks: is it only the lower amount of WM representations retained, or are the representations that OAs hold in WM less precise than those of YAs? Or should one consider the interaction between the numerosity and the content of the representations?

These questions about the role of the content of the representation in the age-related WM decline, and its interaction with the number of representations, are the focus of the present mini-review. Accordingly, in the next sections we describe some of the extant studies on feature binding as a proxy to explore the age-related effect of the content of WM representation (in line with the view of WM as a flexible resource process; Wilken and Ma, 2004; Bays and Husain, 2008). It is well known that the individual features of an object, such as color and shape are first processed separately, and then bound in order to form a complete representation in WM (Treisman, 1986; Schneegans and Bays, 2019). Additionally, the selection and retention of multiple features are more demanding than those of individual features (see Treisman and Gelade, 1980; Treisman, 1988, 1996; Schneegans and Bays, 2019). It is therefore possible that OA's WM impairments may arise as a result of impairments in the binding of multiple features in order to comprise a full representation in WM. Studies on age-related changes in feature binding have used this as a measure to probe the content of WM representations in aging, namely whether OAs demonstrate deficits in the ability to maintain bound object features over short intervals (see Allen et al., 2013 for a review). Finally, and in line with changing views of WM (Ma et al., 2014), we discuss the importance for future investigations to include both set size and feature binding manipulations (as it has been shown in studies on children, see Forsberg et al., 2022) to directly compare the flexible resource vs. fixed slot capacity accounts.

Feature binding and working memory in aging

In this section, we describe the most relevant studies on WM examining the role of feature binding in aging (see Supplementary Table 1). An initial review on this topic (and effects in Alzheimer's Disease; AD) was provided by Allen et al. (2013). For the sake of clarity, we describe the two main types of binding that are typically examined in aging studies (i.e., object-to-location binding and within-object feature binding). We then illustrate those studies that found and those that did not find age-related effects on binding.

In the literature on aging and feature binding, two forms have been considered. The first form of binding is the ability to bind an object to its location. Although there are methodological variations throughout the majority of feature binding studies in aging, the standard paradigm of object-to-location binding presents participants with a small set of target objects. After a short delay, a test object is presented and the participant is required to report whether the object was previously presented (object-only identification), or alternatively, where in the spatial display the object had been presented (location-only identification), or both identity and location features (object-and-location identification) (Mitchell et al., 2000a). This latter condition is theorized to probe object-to-location binding as it measures not only individual feature recall (i.e., object-only and location-only), but also the bound representation of what the object was and where it was in the memorized display. Other investigations of binding have instead explored participants' ability to recall the bound representation of two surface features defining one object (typically color and shape), in comparison to trials in which the recall of single, individual features is required (within-object feature binding, e.g., Brown and Brockmole, 2010). In these studies, participants are presented with a display of shapes in different colors and after a delay, are probed with either individual feature recall of color trials, individual feature recall of shape trials, or both color and shape (constituting the bound representation of the two features; Brown and Brockmole, 2010).

Using a paradigm assessing object-to-location binding, Mitchell et al. (2000a) examined whether OAs showed disproportionate impairments in conditions in which subjects were probed to indicate either only the location of one of three previously presented object drawings (location trials), the object itself (object trials), or whether the exact test probe was presented in the same location as it had been in the previous memory array presentation (i.e., binding trials). The researchers found no age-related differences in location-only or object-only detection trials, but found an age-related decrement when both object and its location had to be recalled. In line with this study, Cowan et al. (2006) investigated OAs performance in a WM task probing memory for colored squares presented in different locations. In this task, in one condition one of the colored squares presented in a memory array changed in the test array to a different color (individual feature recall), while in the other condition, one of the colored squares presented in the memory array then changed to match another color present in the test array (binding condition). This binding condition should test the participants' ability to create bound representations of the object and its correct location. The researchers found an age-related effect in binding memory conditions when individual feature recall trials and binding trials were intermixed within the same block. The results of Mitchell et al. (2000a) and Cowan et al. (2006), suggest that object-to-location binding was specifically affected by age in comparison to trials in which those features were recalled individually.

The age-related decrement is replicated in some studies where features are required to be recalled within an object (i.e. within-object feature binding). For instance, Brown and Brockmole (2010) investigated age-related effects on binding color and shape in two experiments, and found an age-related difference for binding trials (Experiment 2; Brown and Brockmole, 2010). In line with these results, further research has also found age-related effects of feature binding of color and shapes (Brockmole and Logie, 2013; Experiment 3 of Brown et al., 2017). Additionally, binding impairments are evident in experiments probing the precision of OAs WM representations (Peich et al., 2013; Mitchell et al., 2018). In these studies, performance was measured through response dials requiring the most precise estimate of either color and orientation of previously presented colored bars at different orientations (Peich et al., 2013), or through a response color wheel that the participant had to adjust to recall the color of a previously presented probe item (Mitchell et al., 2018).

Notably, not all studies have provided positive results on aging and feature binding. Several investigations have not found a specific age-related effect on binding, either in within-object feature binding (Brockmole et al., 2008; Experiment 1 of Brown and Brockmole, 2010; Parra et al., 2009; Rhodes et al., 2016; Experiments 1 and 2 of Brown et al., 2017; Killin et al., 2018), or in object-to-location binding of complex fractals (Pertzov et al., 2015), or feature-location binding of shapes (Read, Rogers and Wilson, 2016). Similarly, in a more recent follow-up of Cowan et al. (2006) study (investigating more specifically both color and shape conjunction detection and color and location detection) Rhodes et al. (2017) found that the detection of feature binding was not disproportionately affected by aging.

One explanation proposed to account for the discrepant results is that recall of bound features declines in aging to the same extent as for individual feature recall. For instance, Brockmole et al. (2008) found that, although OAs showed significant differences between conditions of individual color recall and binding conditions, there were no significant differences between individual shape recall and binding conditions. This led the researchers to suggest that OAs difficulties arise from an impairment in maintaining shapes, not from a particular deficit in the bound representation of shape and color. Notably, this finding was also replicated by Isella et al. (2015) with a larger sample size. Brockmole and Logie (2013) and Pertzov et al. (2015) came to similar conclusions, proposing that the differential age-related effects of binding found in their study were comparable to age-related WM decline overall (Brockmole and Logie, 2013) or due to a decline in forgetting objects altogether (Pertzov et al., 2015), as opposed to a specific deficit in recalling bound representations. Further potential explanations for the discrepant findings across the studies investigating binding in healthy aging have included small sample sizes in earlier studies (see Isella et al., 2015), and the possible involvement of verbal mechanisms that OAs may recruit to compensate for declining visual WM (Forsberg et al., 2019). Forsberg et al. (2019) proposed that verbal mechanisms would be effective when a small amount of information needs to be recalled (i.e., one feature), but such compensatory mechanisms would not suffice when multiple features (i.e. bound representations) need to be recalled. Moreover, the various methodological differences across these binding studies (see Supplementary Table 1) could explain the heterogeneity of findings.

The interaction with set size

Recent WM studies and models (Bays, 2014, 2019; see also Bays, 2015, Schneegans and Bays, 2017; Schurgin et al., 2020) have focused on aspects (such as item similarity, item familiarity, and neural noise) that converge in highlighting the role of the content of object representations to explain WM. Additionally, Bays (2014; see also Bays, 2015) and Schurgin et al. (2020) found associations between measurements of the content of object representations and set size. Altogether, the emerging view on WM in young adulthood indicates that (a) the content of the representations has a role in determining WM efficiency, and (b) the interaction between the quality and quantity of the maintained representations is a critical aspect to fully predict WM functioning.

In line with these recent accounts, we propose that assessing simultaneously the role of quantity (e.g., by means of set size) and quality (e.g., by means of feature binding) in WM performance of OAs would help unveil the nature of the age-related WM decline. However, most of the studies on age-related changes in WM have examined the impact of set size on performance (e.g., Jost et al., 2011; Sander et al., 2011; Ko et al., 2014), while only a few studies (reported above) have addressed the role of feature binding, or their interaction, in the age-related decrement (Supplementary Table 1). Among the latter ones, Cowan et al. (2006; Exp. 1a) used a varying set size of elements and found a significant interaction between age, array size and memory condition (individual item recall vs. binding conditions). OAs showed an impaired performance even for the lowest set size (four) in comparison to the individual item recall. In contrast, YAs only had a detrimental binding performance for the larger set arrays. Although these results should be interpreted with caution (see Rhodes et al., 2017), they suggest that also in YAs there is an impact of recalling fully bound representations; however, this detrimental effect is evident only when there are more items to retain. In contrast, for OAs, feature binding and set size seem to have additive effects. Indeed, the content of the representations to maintain has a detrimental effect even with a low number of items to recall - OAs may have an impaired ability to fully represent items already at low set sizes, in comparison to YAs (Cowan et al., 2006). Rhodes, et al. (2017; Exp. 1) also found a significant interaction between age, set-size and memory condition (individual feature recall of color and shape vs. binding condition). For both age groups, the binding and shape conditions were more difficult (in comparison to the color condition); however, in OAs the decline in performance with item increase was less enhanced than in YAs. This was evident only when shape was the critical feature (namely, for the shape recall and binding conditions). Therefore, the authors concluded that feature binding does not consistently interact with set size in determining the performance decline of older individuals.

Although these initial findings suggest that there might not be a significant interaction between set size and binding in aging (see also Brockmole et al., 2008; Exp. 1; Mitchell et al., 2018), one should consider that to date the studies investigating feature binding abilities in aging *per se* have provided mixed results, and for this reason it is difficult to reach a definitive conclusion. Furthermore, the variations in experimental design across these studies additionally make it difficult to interpret the results. For example, Cowan et al.'s (2006) object-to-location binding included the presentation of a duplicate color in the test array, whereas individual feature trials included the presentation of a new color to the test array. This is in opposition to

Brockmole and Logie (2013) in which subjects were probed to identify the color, shape and location of objects. Differences in methodologies were also present across within-feature binding studies manipulating set size (see Brockmole et al., 2008; Exp. 1 and Read et al., 2016; Exp. 2).

Concluding remarks

As we have summarized in this mini-review, further research is warranted before making a conclusive argument for or against the presence of age-related effects on feature binding, and its interaction with set size. More in general, it remains unclear what specifically declines in aging during WM tasks, in terms of the contribution of the content and quantity of the representations to the age-related differences in performance.

Since feature binding is strongly associated with attention, one key aspect to consider is the role of attention in the age-related binding and WM decline. As attention deficits are well documented in aging (Gazzaley et al., 2005; Craik and Bialystok, 2006; Madden, 2007), the inclusion of tasks assessing attention in feature binding in aging studies would be of utmost importance (although some studies failed to show such a link, see Brown and Brockmole, 2010). A paradigm based on the Theory of Visual Attention (TVA; Bundesen, 1990), can provide measures of speed of information processing (*C*) and visual short-term memory (vSTM capacity; *k*) using a "whole report" task (Bundesen, 1990; McAvinue et al., 2012; Wiegand et al., 2014), suggesting its applicability to being included in feature binding assessments considering the involvement of attention. In TVA-based paradigms, *C* provides an estimation of the speed of encoding items into VSTM (McAvinue et al., 2012), and accordingly, in the investigation of feature binding in aging, could provide an assessment of the speed of encoding object representations across binding and single feature trials. Additionally, *k* could provide a useful estimation of the amount of representations encoded into vSTM. Wiegand et al. (2014)

found OAs with lower *C* to indicate a reduction in a neural measure associated with the prioritization of object features relevant to a task (Töllner et al., 2009). The researchers concluded declining attention abilities in aging to be associated with a slowing of object encoding. Utilizing a TVA-based paradigm could provide a useful assessment of both the processing speed of encoding object representations (*C*) and the amount encoded into vSTM (*k*), in the investigation of feature binding in aging.

A second issue for future research pertains to the neural mechanisms involved in the age-related changes in feature binding. A proposal has been discussed (Parra et al., 2009; Isella et al., 2015; Rhodes et al., 2017) theorizing object-to-location binding may be more impaired than within-feature binding in aging. Object-to-location binding has been found to involve enhanced activation of the hippocampal region (Piekema et al., 2010), an area that is known to degrade in healthy aging (Raz and Rodrigue, 2006). Indeed, the hippocampal area degrades with age more than temporal, occipital and parietal regions, which have instead been found to underlie within-feature binding in YAs (Parra et al., 2014). This is further supported by findings that OAs have shown reduced hippocampal activation in comparison to YAs when completing an object-to-location feature binding task (Mitchell et al., 2000b). However, this proposal cannot accommodate all of the existing results, as not all of the object-to-location binding studies found this type of binding to be impaired in aging (see Supplementary Table 1).

The examination of feature binding in aging is also pertinent for clinical reasons. Indeed, feature binding of WM representations has been proposed as a marker for AD (Parra et al., 2010, 2011; Cecchini et al., 2022 for a review) and for individuals at vascular risk (Bika et al., 2021). Research has found individuals with AD, and asymptomatic carriers, to indicate decreased hippocampal volume associated with object-to-location binding impairments (Liang et al., 2016). Additionally, individuals with AD, and asymptomatic carriers, have demonstrated impairments in within-feature binding (Parra et al., 2010, 2011). Evidently, the importance of examining feature binding in aging extends beyond developing a more comprehensive understanding of WM in healthy aging, and may help develop screening tools to distinguish against pathological aging.

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Conflict of interest

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Supplementary material

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Chapter 3

Aging and Visual Working Memory for Real-World Objects

3.1 Introduction

Visual working memory (vWM) is known to decline during aging (Brockmole & Logie, 2013; Cabeza et al., 2016). These age-related impairments are exemplified through lowered amount of items or features that OAs are able to recall from memory in tasks such as Change Detection Tasks (CDT; Ko et al., 2014; Sander et al., 2011). In a CDT paradigm, participants are presented with a varying number of to-be-remembered elements; after a short delay, observers are probed to respond whether the current display contains the same elements, or whether there has been a change (Luck & Vogel, 1997).

It remains unclear however whether declines in aging using a CDT are due solely to a fewer amount that OAs are able to recall, or whether there is a decline in aging of the object content as well. One manner in which age-related decline in object content compared to only lower WMC has been investigated, has been in the investigation of OA's "precision" of geometrical stimuli held in WM, such as oriented and colored bars and abstract fractals (Mitchell et al., 2018; Peich et al., 2013; Pertzov et al., 2015). Interestingly, these studies have found OAs have a declined precision of memory for items compared to YAs, even when only one item has been kept in memory (Mitchell et al., 2018), and such declines were exacerbated with even more items (Peich et al., 2013; Pertzov et al., 2015).

Peich et al. (2013) implemented a dual feature WM task (Bays, Wu, & Husain, 2011) to examine the resolution of OA's maintenance and recall of features bound together in each item previously presented. For this investigation, OAs and YAs were presented with trials consisting of either one or three differently colored bars set to different spatial orientations; during a test array they were presented with one bar that they would need to adjust using two dials, corresponding to the color and orientation features of one of the previously presented bars (Peich et al., 2013). The researchers found a detrimental age effect in the precision recall of both reports (color and orientation) when only one item had been presented in the memory array, suggesting memory precision to be declined in OAs when only one item is in memory (Peich et al., 2013). Furthermore, when there were three bars presented in the memory array, Peich et al. (2013) also found a significant age interaction (a stronger effect compared to the one item condition), suggesting that higher memory load decreased OA's precision with which items are represented in memory. Importantly, although these declines in the precision of items held in memory were present for both groups, the effect was significantly worse for OAs (Peich et al., 2013). Moreover, the researchers also examined how frequently features were incorrectly reported as belonging to the target bar, when in fact those features had belonged to another item in a different location: also known as binding errors between location and item. The researchers found these errors to be highest for OAs (Peich et al., 2013). Overall, it appears OAs commit more errors in individual feature reports of color and orientation and in confusing the item and location (committing binding errors). Although binding is not the focus of the current set of experiments, it is important to mention the investigation of possible age-effects not only related to the individual recall of certain features. Moreover, the findings of Peich et al. (2013) appear to suggest as well that age-related declines in the precision for item memory is not only exacerbated with more items in memory, but also, precision declines occur even with only one item, suggesting the precision of memory declines in aging, not just the amount.

Also with the aim of investigating the precision of WM in aging, Pertzov et al. (2015) presented OAs and YAs with one or three abstract fractals in different memory arrays and then in a following test array presented one of the same fractals along with another new fractal that had not been presented in the previous array. Once the participant had responded to which fractal they believed had been previously presented, the participant would need to drag the selected fractal to the previously presented position signifying bound recall of item and location (Pertzov et al., 2015). Although the researchers did not find an increased object-location binding effect in aging, they found that both object and location recall declined more in OAs. This age-related memory precision decline also occurred even in trials in which one fractal was presented, therefore the researchers theorized that this suggested, along with the findings of (Peich et al., 2013), that memory decline in aging is not only the result of a higher amount of items that need to be retained, but also by the precision of the memory for those items (Pertzov et al., 2015). Furthermore, the higher amount of items (3 fractals), led to a more disproportionate decrease in performance for OAs than YAs (Pertzov et al., 2015). Evidently, it appears these findings, along with those of Peich et al. (2013), suggest a decline in aging in the precision of memory representations with more items in memory, however, the precision of representations may already be declined when only one item is in memory. Mitchell et al. (2018) also investigated OA's precision recall using colored dots and asking participants to adjust the color of a target dot using dials during the test array presentation. The researchers found that OA's had less precise recall overall and also incorrectly reported bound representation of color and correct position more frequently than YAs.

The results across these studies, using different types of geometrical stimuli, appear to suggest memory precision in aging to decline (Mitchell et al., 2018; Peich et al., 2013; Pertzov et al., 2015). In particular, the findings of both Peich et al. (2013) and Pertzov et al. (2015) suggest these age-related declines in precision to occur even when only one item is retained and to decrease in OAs when more items were presented.

If OAs have less robust representations of items held in WM, as is suggested by the previous studies using geometrical stimuli (Mitchell et al., 2018; Peich et al., 2013; Pertzov et al., 2015), it is therefore possible that the well-founded result in aging that is reported when using CDTs, may not only be the result of less items that OAs are able to retain and recall, but may also be the result of less precise representations. Accordingly, I wanted to examine this question in the current study. Moreover, my aim was to utilize real-world objects for this question in order to investigate whether possible age-related impairment of the precision of WM representations expand when real-world objects are the stimuli to maintain and recall. Furthermore, the implementation of real-world objects is more applicable to everyday situations, and also is being used more frequently in YA and memory research (Asp et al., 2021; Brady et al. 2016), reinforcing the interest in using this type of stimuli for the current study.

Current Study

In summary, the overall aim of these two experiments was to investigate whether in aging there is a possible influence of the content of real-world object representations using a CDT. Accordingly, to this aim, I examined different levels of similarity (high and low similarity) between the objects presented in the display. Interestingly, research in young adults (YAs) has suggested that increased similarity amongst items can improve YA's performances (see Lin & Luck, 2009). Furthermore, as real-world objects can be considered as comprised of multiple features, I therefore examined similarity between objects in two different features: conceptual and perceptual. Conceptual features as used here is the category that the object could belong to (for example, a shirt being a clothing item). Perceptual feature in the current study was color. Relating back to the previously described studies in which the precision of items held in vWM declined with an increased amount of items (Mitchell et al., 2018; Peich et al., 2013; Pertzov et al., 2015), my second aim was to include manipulations of numerosity in the current experiments in order to investigate possible interactions.

Accordingly, the aim of Experiment 1 was to investigate OA's vWM performances in a CDT with **conceptual** similarity (high and low similarity) and **numerosity** manipulations (2 or 3 objects). Experiment 2 was conducted to investigate OA's performances in a CDT with

perceptual similarity (high and low similarity) and **numerosity** manipulations (2 or 3 objects). In both experiments, through using CDTs with similarity manipulations as a proxy for measuring object content representation, I aim to examine whether the amount, as well as the quality of object representations differentially influence OA's vWM performances.

Key predictions for this investigation could be that OAs have significantly worse performances than YAs when there are more real-world objects to retain and recall, reflecting a plethora of previous research using geometrical stimuli (Ko et al., 2014; Sander et al., 2011). Regarding the similarity manipulation, when there is a high amount of similarity between items, this may be more detrimental to OA's performances in this CDT as it has been found that OAs take longer to respond when items have more features in common (Scialfa & Thomas, 1994). Moreover, more recent research has found OAs to more falsely recognize objects that have not been presented before, but that contain similar features to those previously presented before (see Boutet et al., 2019; Pidgeon & Morcom, 2014). Accordingly, it is possible in the current experiments, that the similarity conditions with high similarity, lead to less accurate responses from the OA sample as this group may be less likely to individuate the objects and correctly respond. Whether this would more likely occur in the perceptual or conceptual similarity conditions, is exploratory, as previous studies have found age-differences in the memory recall of items manipulated in both aspects (see Boutet et al., 2019; Koutstaal et al., 2003; Pidgeon & Morcom, 2014). Importantly, to the initial aim of this thesis project, it is theorized that the influence of the high similarity conditions (**conceptual** and **perceptual**) will interact when there are more objects to retain (higher **numerosity** conditions).

Experiment 1: Change Detection Task with Conceptual Similarity

In Experiment 1 I tested older and young adults' in an online change detection task (CDT; Luck & Vogel, 1997). In this task, participants were first told to attend to one side of a memory array and then were presented on the cued side of the screen with either two or three images. On the un-cued side, images were presented that the participant would need to disregard. In each trial, the amount of these images on the un-cued side was equivalent to the amount on the cued side. Next, after a brief maintenance period delay, participants were then presented with a test array. In this test array, the same amount of objects were presented again and participants were asked to respond whether a change had occurred in the images from the first memory display to the test array display. Importantly for the current study, in each memory and subsequent test array, the images were related to the other images in the display in conceptual similarity ("high conceptual similarity": same category), or were un-related to each other ("low conceptual similarity": from a different category); see Cimminella et al. (2020) for similar work done with real-world objects and manipulations of categorically similar and dissimilar stimuli in young adults. The second main manipulation in Experiment 1 was the numerosity of the cued images in the display, either two or three images. Given these manipulations, I was able to examine possible age differences in a CDT with respect to the amount as well as the content of the representations presented.

3.2 Experiment 1 Method

3.2.1 Participants

All participants were recruited online through Prolific (www.prolific.co). For this experiment, I tested young adults (n = 32; aged 20-30) and older adults (n = 36; aged 65-75). Previous aging studies have tested similar sample sizes for between group comparisons (Jost et al., 2011), suggesting this amount to be promising in revealing possible age effects in performances. Data from 5 older adults were removed from the final analysis due to scoring below the minimum score on the administered cognitive battery (SATURN Bissig, Kaye, & Erten-Lyons, 2020; see below), leaving 31 OAs for the final analysis. After calculating outliers (see section 3.2.4 below), there were 30 YAs for the final analyses (m = 25.13, SD = 3.32, 23 Female) and 27 OAs for the final analyses (m = 68.63, SD = 2.68, 10 Female).

All participants could only take part in the study using a Desktop computer (no mobile phone or tablet) and were recruited from Prolific's option of "All countries available" as well as from a "Standard sample" which allows for the study to be distributed to all available participants with the only restrictions being the other experimental criteria explained below.

For young adults (YAs), I set the inclusion criteria that participants must be between 20 and 30 years old and their first language must be English in order to be eligible to take part in the study. For older adults (OAs), the inclusion criteria were that participants must be between 65 and 75 years old, first language must be English and they have never been diagnosed with mild cognitive impairment (MCI) or dementia. General demographic information including age and gender is listed in **Table *1***.

All participants were reimbursed 7.50 sterling pounds an hour. After agreeing to take part in the experiment in Prolific, participants were all passed on to Psytoolkit (psytoolkit.org) to give their informed consent. The study was approved by the Università degli Studi di Trento Research Ethics Committee (Protocol No: 2020-021).

3.2.2 Stimuli and Apparatus

All stimuli were downloaded from the online repository of Aude Oliva Lab at MIT (http://olivalab.mit.edu/MM/index.html). The object images used in this study were collected from the "Object Categories" repository (cited in Konkle, Brady, Alvarez & Oliva, 2010). Some of the images' colors were edited in Adobe Photoshop, please see Appendix A for image details. Each of the 72 objects were divided into four main object categories: 1) Tools / Appliances, 2) Furniture, 3) Cook / Tableware and 4) Clothing. The images determined to belong to each of these categories were predetermined through a series of previously conducted pilot studies using a separate set of subjects (see Appendix A), however in the same age ranges for older (65-75 years old) and young adults (20-30 years old). Moreover, each of the four categories were sub-divided into two sub-categories, determined by the researchers. For example, within the "Tools / Appliances" category, the two sub-categories were a) "Electrical" and b) "Non-Electrical" Tools and Appliances, for example, a washing machine and an axe, respectively.

Objects were 4 x 4 cm and were presented within a 4-quadrant display, each presented with a 0.30-degree jitter on a blank white screen (RGB values: 255, 255, 255) with a black fixation cross (RGB values RGB: 0, 0, 0) in the center of the screen. In order to ensure that in this online experiment, each object was presented at the same pixel resolution according to the participant's computer dimensions, an additional step to the set-up of the experimental procedure included a "credit card slider" (Li, Joo, Yeatman, & Reinecke, 2020 and https://gitlab.pavlovia.org/Wake/screenscale). The purpose of this slider is to calculate the size of the participant's computer screen. For this implementation, participants were first asked to sit at an arm's length distance from the computer and were presented on their screen with a virtual credit card and instructed to hold a physical bank card to the screen and adjust the virtual card to be the same size as their physical card. Based on these provided dimensions, a calculation is then used by the program to determine the size of the participant's screen as well as the pixels per centimeter (cm) of their computer.

3.2.3 Design and Procedure

After completing the initial recruitment in Prolific, participants were passed to Psytoolkit (psytoolkit.org; Stoet, 2010, 2017) in order to provide their informed consent. In Psytoolkit, participants were shown the Information Sheet as well as the final consent guidelines and provided their informed consent by clicking a button "YES, I consent" and proceeded to the main experiment. Next, OAs completed the online screening battery SATURN. In this cognitive screening test (SATURN; Bissig et al., 2020), OAs were assessed on their cognitive ability. The main domains that are assessed are: Attention, Orientation, and Memory. After completing the SATURN test, all OAs were then passed to the main task. Scores were assessed after participants went through the whole procedure (including the main task) and were only excluded from the final analysis if they received a score below 26 on the Saturn screening test (the cut-off score).

Alternatively, if the subject was a YA, they were automatically passed to the main task. The main experiment was created in Psychopy® (v2020.2.10; Peirce et al., 2019), with MATLAB and JavaScript code and hosted through Pavlovia (Pavlovia.org, Pavlovia Surveys; Open Science Tools, Nottingham, UK).

Table 1

General demographics for participants in the Experiment 1 Change Detection Task with Conceptual Similarity

	Young adults	Older adults
	n = 30	n = 27
Age	m = 25.13 yrs. SD = 3.32	m = 68.63 yrs. SD = 2.68
Gender		
Female	23	10
Male	7	17
Saturn	n.a	m = 27.63 SD = 1.18

Note. Demographic information includes final sample analyzed after excluding outliers.

yrs. = years

n.a = not applicable

m = mean

SD = standard deviation

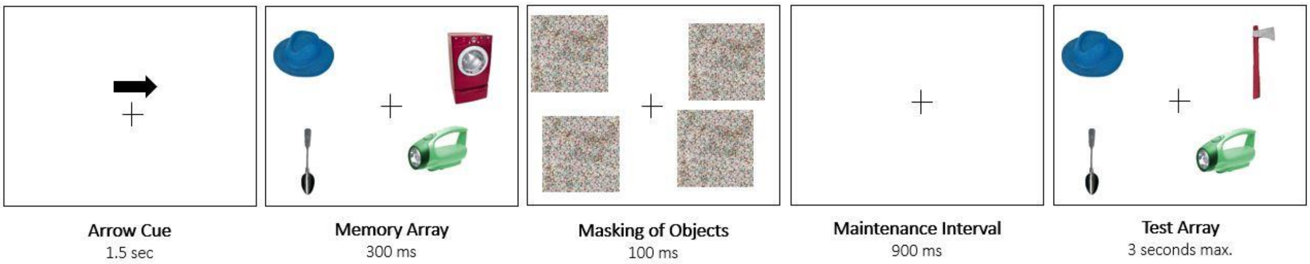
After determining the dimensions of their computer, participants then continued to the main instructions. Participants were asked to align themselves with the center of the screen and instructed that for the entire duration of the experiment there would be a cross presented in the center of the screen, and that they should fixate on this cross during the different stages of the task procedure. Participants were then told there would be an arrow pointing either to the left or right-hand side of the screen on a following screen (indicating the side of the screen that they must direct their attention to, without moving their eyes from the cross in the center). Next, participants were told that objects would be briefly presented on the screen, and that they should memorize only the objects on the side of the screen that was previously indicated by the arrow. The participants were then instructed that the objects would disappear quickly and then following a short delay, another screen would be presented in which they needed to indicate whether the objects on only the cued side were the same as the previously presented objects, or whether one changed. The participants were told that they had a maximum of 3 seconds in which to respond on their keyboard ("c" for a change in the image display or "m" if there was no change). The task was meant to be unspeeded, namely it was not stressed to the participants the importance of giving fast responses. They were then told that after they gave their response, a new trial would begin and if they did not respond within the 3 second response time, a new trial would automatically begin. Participants started the experiment with 16 practice trials.

During the first eight practice trials, the fixation cross in the center of the screen turned red when the participants needed to respond (during a 3 second response screen). The following eight practice trials replicated the main experiment in which the fixation cross would remain black, replicating the actual task. Participants were given feedback whether they had responded correctly or incorrectly throughout the practice trials after responding.

For the experiment, there were 30 possible experiment files that each participant would randomly be assigned before starting the experiment, ensuring that not all participants had the same image presentations throughout the experiment. See Figure *9* for the experimental set-up. The arrow cue presentation above the fixation cross was presented for 1500 milliseconds (ms). Next, the memory array was presented for 300 ms, and masked for 100 ms. Next, a blank screen with a fixation cross was presented for 900 ms, signifying the maintenance interval. Then the test array was presented (where there could either be a change or no change to one of the items and during this display, the subjects had up to 3 seconds to respond. Maximum time for responding was 3 seconds. Intertrial interval was 1 second.

Figure 9

Change Detection Task Experiment Example



Note. Images not to scale.

Sec.: seconds

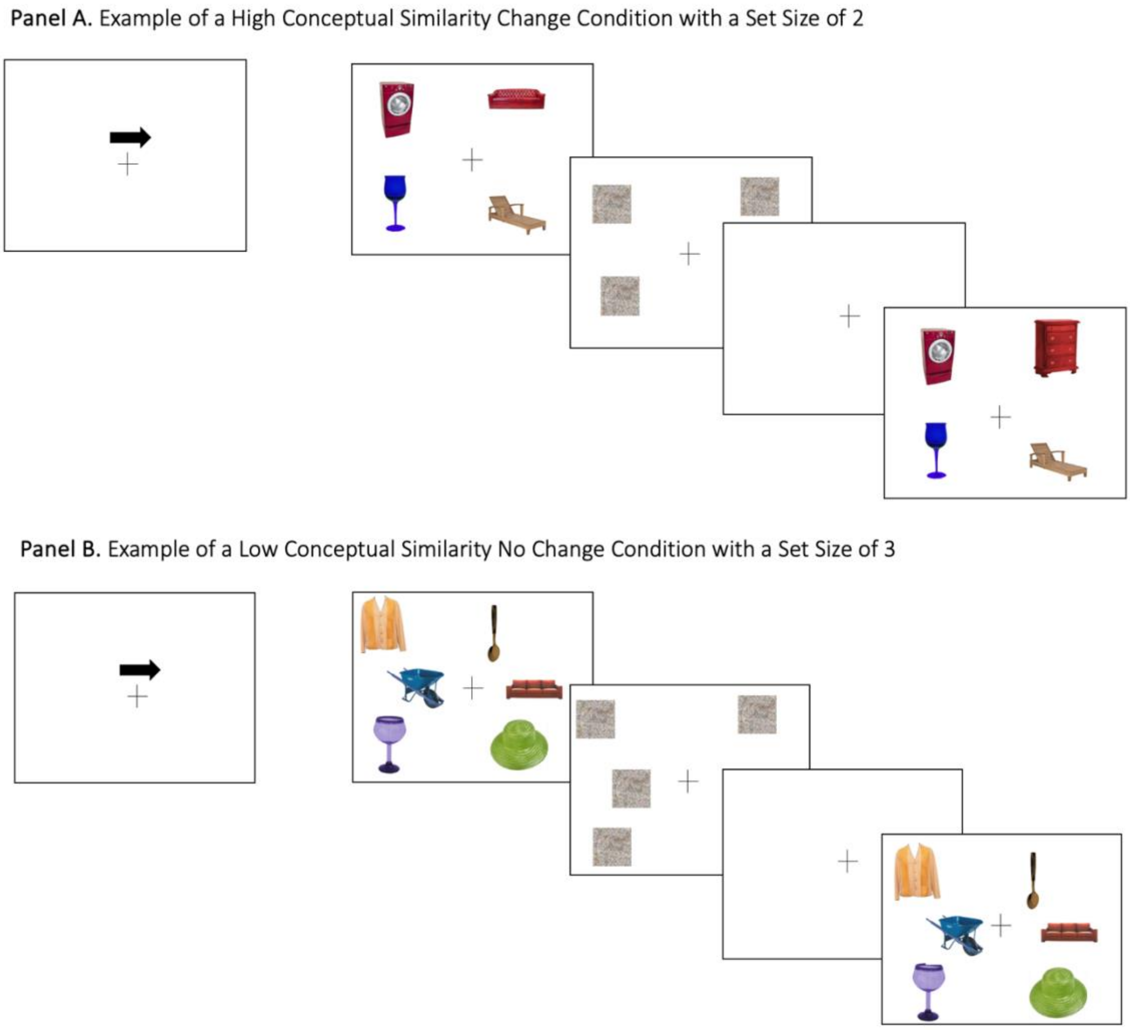
In this experiment, the main manipulations of interest were similarity and numerosity. Accordingly, there were two levels of conceptual similarity: high and low similarity and two levels of numerosity: 2 objects on the cued side or 3. These manipulations equated to four main conditions of interest: 1) Low Conceptual Similarity, Numerosity 4; 2) Low Conceptual Similarity, Numerosity 6; 3) High Conceptual Similarity, Numerosity 4: 4) High Conceptual Similarity, Numerosity 6. High conceptual similarity conditions contained only objects belonging to strictly one of the four categories, while the low conceptual similarity conditions contained objects from each of the four conditions (with no overlap between object category). There were 288 total trials, with 72 trials in each of these four main conditions. Moreover, half (36 trials) of these four main conditions had the cued images on the left-hand side of the screen and half (36 trials) on the right-hand side of the screen. Participants were given the option every 50 trials to take a break throughout the experiment if needed.

Conditions of Low Conceptual Similarity included objects presented in the memory array (on the cued side) that were from a different category as the other images presented on the cued side (of the above four categories; see Figure *10* Panel B). Additionally, the probe image that changed on half of the trials was an image that was from the same category (therefore not signifying a pop out – making the trial too easy) as well as the same color (see the red washing machine change into the red axe in Figure *9* above; see also Appendix A for change item details and color details). The changing probe image belonged to the same category, however was from the alternate sub-category as the image it was "replacing" in the display (see Appendix A). For example, if the probe to change on a trial was a fan (electrical Tool/ Appliance), this probe would change to a wheelbarrow (non-electrical Tool/ Appliance).

Conditions of High Conceptual Similarity included objects presented in the memory array (on the cued side) that were from the same category (of the above four categories: see Figure *10* Panel A). The probe image change to a sub-category change was the same in High Conceptual Similarity conditions as described above for Low Conceptual Similarity conditions. When needed, probe change items were oriented to be presented at the same orientation as the image it would replace. Probe position was controlled for and presented equally in all 6 of the possible spatial locations. Finally, all of the conditions, low and high similarity and change or no change trials were all counterbalanced to also implement the second main manipulation of numerosity: therefore, across all of the criteria described above, each condition also had either 2 items presented on the cued side (4 images presented on the screen in total, including the un-cued side with randomized images) or 3 items presented on the cued side (6 images presented on the screen in total, including randomized un-cued side images).

Figure 10

Change Detection Task with Conceptual Similarity



After completing the main experiment, participants were then returned back to Prolific with a completion code. In general, for the full procedure of the study YAs took on average 35 minutes and OAs took 44 minutes.

3.2.4 Data analysis

Analyses of this CDT were first conducted using MATLAB code and Excel to determine accuracy. Data from two YAs were removed for being outliers based on their accuracy, leaving 30 YAs for the final analyses (mean age = 25.13, SD = 3.32, 23 Female). Outliers were determined using the Inter-Quartile Range (IQR) method which was calculated in Excel, in which a normal data range is calculated based on all subject's averages and then outliers are determined by those who have responses above or below this normal range (Rousseeuw & Croux, 1993; Yang, Rahardja, & Fränti, 2019). Of the 31 OAs that had a score of 26 or above in Saturn, four additional OAs were then removed from the analyses for being outliers, leaving 27 OAs for the final analyses (mean age = 68.63, SD = 2.68, 10 Female).

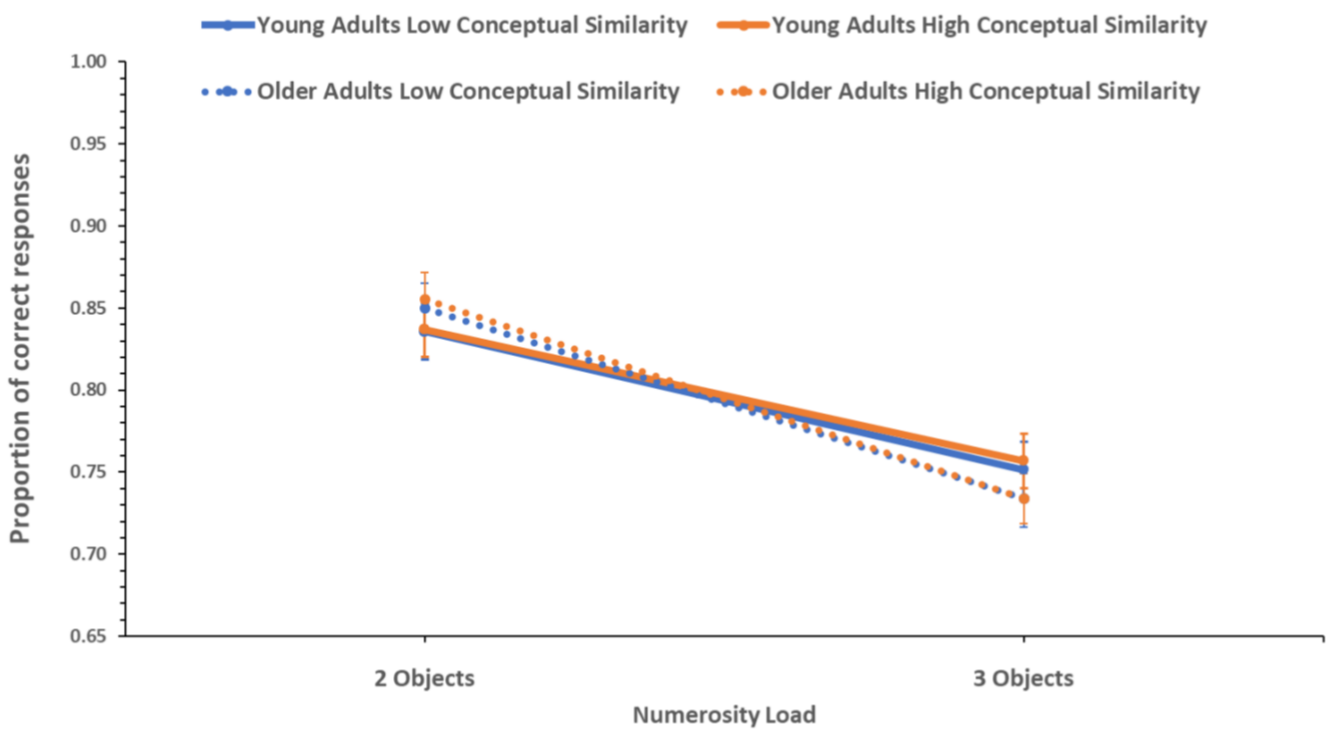
To analyze the accuracy values of both age groups, repeated measures ANOVAs on correct responses were conducted in JASP (http://www.jasp-stats.org) with the between-subjects factor of age group (OA, YA) and the within-subjects factors of Similarity (low, high) and Numerosity (2, 3). Bayesian statistic ANOVAs were also conducted using JASP (Van Den Bergh et al., 2020). Bayes Factor 10 (BF_{10}), which is the value of the likelihood of the alternative model compared to the null model, is reported following the results of the corresponding ANOVA results. A Bayes Factor (BF_{10}) higher than a value of 1 is considered as evidence in favor of the alternative hypothesis, whereas less than 1 is evidence in favor of the null hypothesis. Significant effects or interactions were then investigated further with independent samples t-tests for group comparisons or paired samples t-tests to investigate further within-groups. Each of these tests had false discovery rate corrections applied (FDR; Benjamini & Hochberg, 1995) and were all performed in MATLAB (Groppe, 2023, MATLAB FDR script).

3.2.5 Results

A repeated measures ANOVA on accuracy values (see Figure *11*) found no significant effects of similarity, $F(1, 55) = 0.317$, $p = 0.576$, $\eta p2 = .006$, $BF_{10} = 0.152$, similarity by age group interaction, $F(1, 55) = 0.003$, $p = 0.954$, $\eta p2 < .001$, $BF_{10} = 0.040$, or interaction between similarity, numerosity or age group, $F(1, 55) = 0.140$, $p = 0.710$, $\eta p2 = .003$, $BF_{10} = 2.524e+29$. There was no significant interaction between similarity and numerosity, $F(1, 55) = 0.003$, $p = 0.955$, $\eta p2 < .001$, $BF_{10} = 6.451e+29$. Additionally, there was no overall between subjects age effect, $F(1, 55) = 0.009$, $p = 0.927$, $\eta p2 < .001$, $BF_{10} = 0.276$.

Figure 11

Young and Older Adults Proportion of Correct Responses in Conditions of High and Low Conceptual Similarity and Numerosity of 2 and 3 in Experiment 1 Change Detection Task



Note. Dotted lines correspond to older adult's (OA) proportion of correct responses, whereas solid lines correspond to young adult's (YA) responses.

There was a significant main effect of **Numerosity**, $F(1, 55) = 210.682$, $p < .001$, ηp2 = 0.793, $BF_{10} = 4.120e+30$. Post hoc comparisons with FDR correction found the set size condition 2 to be significantly different from the set size 3 condition (p<.001). Both OAs and YAs had significantly lower accuracy in the set size 2 condition than the set size 3 condition.

A significant interaction was also found between **Numerosity and group**, $F(1, 55) = 6.925$, $p = 0.011$, ηp2 = 0.112, $BF_{10} = 1.525e+30$. Independent samples t-test post hoc with FDR corrections were conducted and this found however that neither set size 2 or set size 3 conditions were significantly different between the two age groups (both ps=0.4505). Considering the two age groups separately, set size 2 was significantly different from set size 3 for YAs (p<.001) and OAs (p<.001).

3.2.6 Experiment 1 Discussion

First, although there was a significant numerosity and group interaction when the repeated measures ANOVA was conducted, the lack of a significant effect during the post hoc independent samples t-test make this difficult to interpret, but it is possible that there was not enough statistical power for a significant age-effect for the individual averaging of the numerosity 2 and numerosity 3 to emerge. The high value of the Bayes Factor for the numerosity by age group interaction ($BF_{10} = 1.525e+30$) suggests the data to be in support of the alternative hypothesis (Van Den Bergh et al., 2020).

Second, in this experiment, both groups had significantly worse performances when there were 3 objects on the cued side of the display, versus when there had been 2 objects. This occurred regardless of whether the real-world objects were high or low in conceptual similarity.

Finally, with regards to the lack of a conceptual similarity effect in this experiment, it is possible that OAs do not demonstrate any difficulties in retain and recalling objects based on varying degrees of conceptual similarity in comparison to YAs, supported by the Bayes Factor results, in favor of the null model. It is interesting to note that there was no effect of high or low conceptual similarity on performances, for either age group. Accordingly, it is worth considering whether the conceptual similarity manipulation as used in this experiment, appropriately examined this question of content of object representation change. Therefore, in the next experiment, I will examine whether high and low perceptual similarity conditions appropriately capture content of object representation, and whether possible effects may be exacerbated in aging.

Experiment 2: Change Detection Task with Perceptual Similarity

In Experiment 2, I assessed whether CDT performance is affected by aging when the perceptual similarity dimension of the images is the manipulation of interest. Accordingly, I manipulated perceptual similarity as the proxy for content of object representation considering two levels: low and high perceptual similarity.

In aging in particular, there may be more of an influence of perceptual dimensions, exacerbating OA's performances when the display contains a higher relationship of perceptual similarity. This has been found in other aging studies using geometrical stimuli (Scialfa & Thomas, 1994). Therefore, in Experiment 2 I expected OAs to indicate worse performances when the display contained all objects of high perceptual similarity to retain and recall. Moreover, I further expected these age-related impairments to then interact with the higher numerosity of objects, based on past vWM research finding OAs to have worse performances when there are more items to retain and recall (Ko et al., 2014).

3.3 Experiment 2 Method

3.3.1 Participants

Recruitment for Experiment 2 of the Perceptual Similarity CDT was the same as Experiment 1; all participants were recruited online through Prolific. For this experiment, I recruited young adults (n = 32; aged 20-30) and older adults (n = 32; aged 65-75). After calculating for any outliers, all 32 YAs were used for the final analysis (mean age = 24.91 years, SD = 2.37, 20 female). One OAs was excluded from the final analysis for being an outlier based on accuracy (outliers were determined in the same manner as in the previous experiment, see 3.2.4). This left 31 OAs for the final analysis (mean age = 68.26 years, SD = 3.42, 19 female).

In Experiment 2 I recruited only subjects that had previously taken part in two previous studies from our group (reported in Tagliabue, Varesio & Mazza, 2022a; Tagliabue, Varesio, Assecondi, Vescovi, & Mazza, 2023), to facilitate data collection. All of the OAs had a cognitive screening score from SATURN (Bissig et al., 2020) of 26 or above, indicating cognitive healthiness.

I amended the recruitment from the first experiment for both age groups to include participants that were fluent (not only native) in English, in order to make the study accessible to more participants. I also amended to the recruitment that both groups for Experiment 2 had to respond to have normal or corrected-to-normal vision (these criteria were already set in the previous studies from our group, along with subjects needing to be either right-handed or ambidextrous). All participants were paid 7.50 sterling pounds an hour.

3.3.2 Stimuli and Apparatus

The stimuli used in Experiment 2 were the same as in Experiment 1 (3.2.2), however with a key change: each of the 72 original images were edited into 4 color groups (black, blue, brown and green; see Figure 12 below), totaling 288 final images. Each of the 72 image objects that I used were edited in Adobe Photoshop into the following four-color groups: 1) black (RGB: 0, 0, 0), 2) blue (RGB: 13, 69, 100), 3) brown (RGB: 104, 53, 2), and 4) green (RGB: 4, 77, 48). The motivation for making these color changes was to have perceptual color groups of the images that are controlled. Some of the original objects were light colored and therefore, in order to have the color groups consistent, the tonal values were also adjusted for some of the images. See Appendix B for a further description. A post hoc visual saliency analysis of the stimuli was also conducted using the Saliency Toolbox in MATLAB (Walther and Koch, 2006) (results of this analysis also in Appendix B). [1]

Figure 12

One Stimuli Exemplar Edited into Each of the Four-Color Groups

[1] A post hoc check for differences in color salience between probe object and accompanying images in the display found no significant difference between color salience.

The configuration requirements for Experiment 2 were the same as in Experiment 1 (sit at an arm's length distance and the credit card slider).

3.3.3 Design and Procedure

The design of Experiment 2 also replicated Experiment 1 (with the change that OAs did not complete SATURN in this experiment).

Table 2

General demographics for participants in the Experiment 2 Change Detection Task with Perceptual Similarity

	Young adults	Older adults
	n = 32	n = 31
Age	m = 24.91 yrs. SD = 2.37	m = 68.26 yrs. SD = 3.42
Gender		
Female	20	19
Male	12	12

Note. Demographic information includes final sample analyzed after excluding outliers.

yrs. = years

m = mean

SD = standard deviation

Experiment 2 replicated Experiment 1 (refer to 3.2.3), with the only difference being the type of similarity as perceptual instead of conceptual. See Figure 13 for an example of Experiment 2. In this experiment, the main manipulations of interest were similarity and numerosity. Accordingly, there were two levels of perceptual similarity: high and low similarity. Akin to Experiment 1, the numerosity could be either two or three images presented on the cued side of the screen, with randomized images of an equal amount presented on the un-cued side. These manipulations equated to four main conditions of interest: 1) Low Perceptual Similarity, Numerosity 4; 2) Low Perceptual Similarity, Numerosity 6; 3) High Perceptual Similarity, Numerosity 4: 4) High Perceptual Similarity, Numerosity 6, with 72 trials in each of the four main conditions, half (36) then with the cued side being the left-hand side of the screen and the other half (36) on the right-hand side. Akin to Experiment 1, there were also 288 total trials fulfilling each of the above described experimental conditions.

Conditions of Low Perceptual Similarity included objects presented in the memory array (on the cued side) that belonged to a different color group than the other images presented on the cued side (of the above four-color groups; see *Figure 12*). See *Figure 13* Panel A for an example of a Low Perceptual Similarity condition.

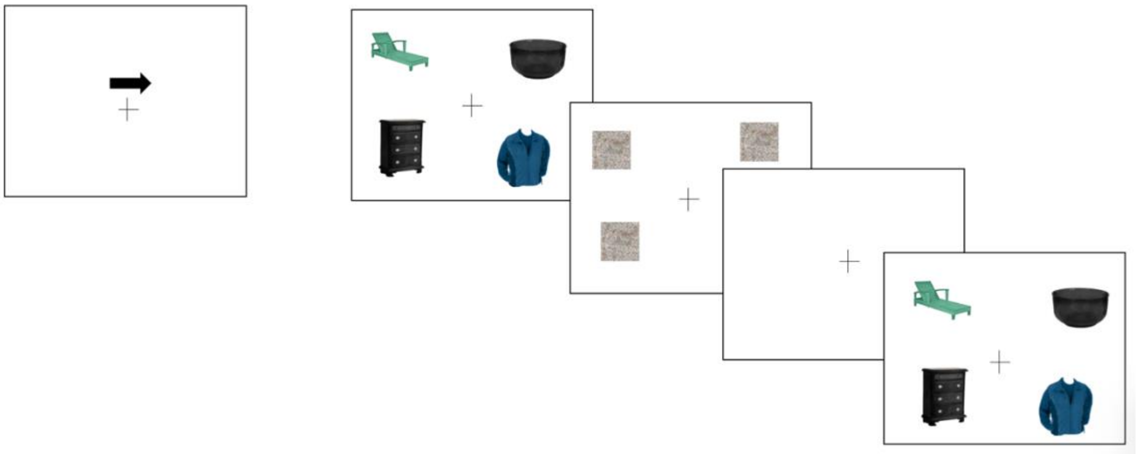
Conditions of High Perceptual Similarity included objects presented in the memory array (on the cued side) which all belong to the same color group (see *Figure 13* Panel B). Probe position was controlled for and presented equally in all 6 of the possible spatial locations. In this experiment, for each condition, the change probe item (on change trials which will consist of half of the total trials) was the same color as the original item that is changing, but it was a different exemplar. Each original probe item and the item it changed into was also the same category (only in the alternate sub-category), as the image it was replacing.

Additionally, all of the conditions; low and high similarity and change or no change trials, were all counterbalanced to also implement the second main manipulation of numerosity: either two or three images presented on the cued side of the screen. Therefore, across all of the criteria described above, each condition also had either 2 items presented on the cued side (4 images presented on the screen in total, including the un-cued side) or 3 items presented on the cued side (6 images presented on the screen in total).

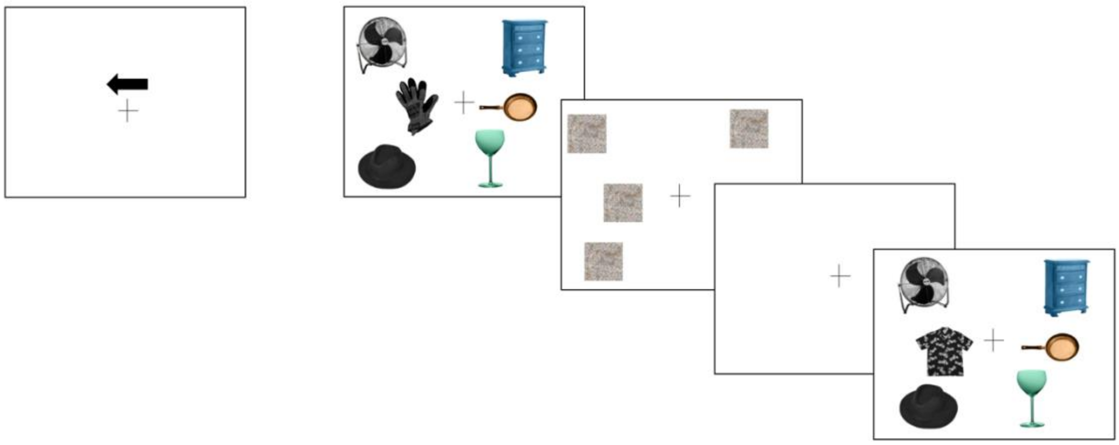
Figure 13

Change Detection Task with Perceptual Similarity Experiment Examples

Panel A. Example of a Low Perceptual Similarity No Change Condition with a Set Size of 2



Panel B. Example of a High Perceptual Similarity Change Condition with a Set Size of 3



Note. Images not to scale.

For the full Experiment 2 procedure (consent and experiment), YAs took on average 39 minutes and OAs took 35 minutes.

3.3.4 Data analysis

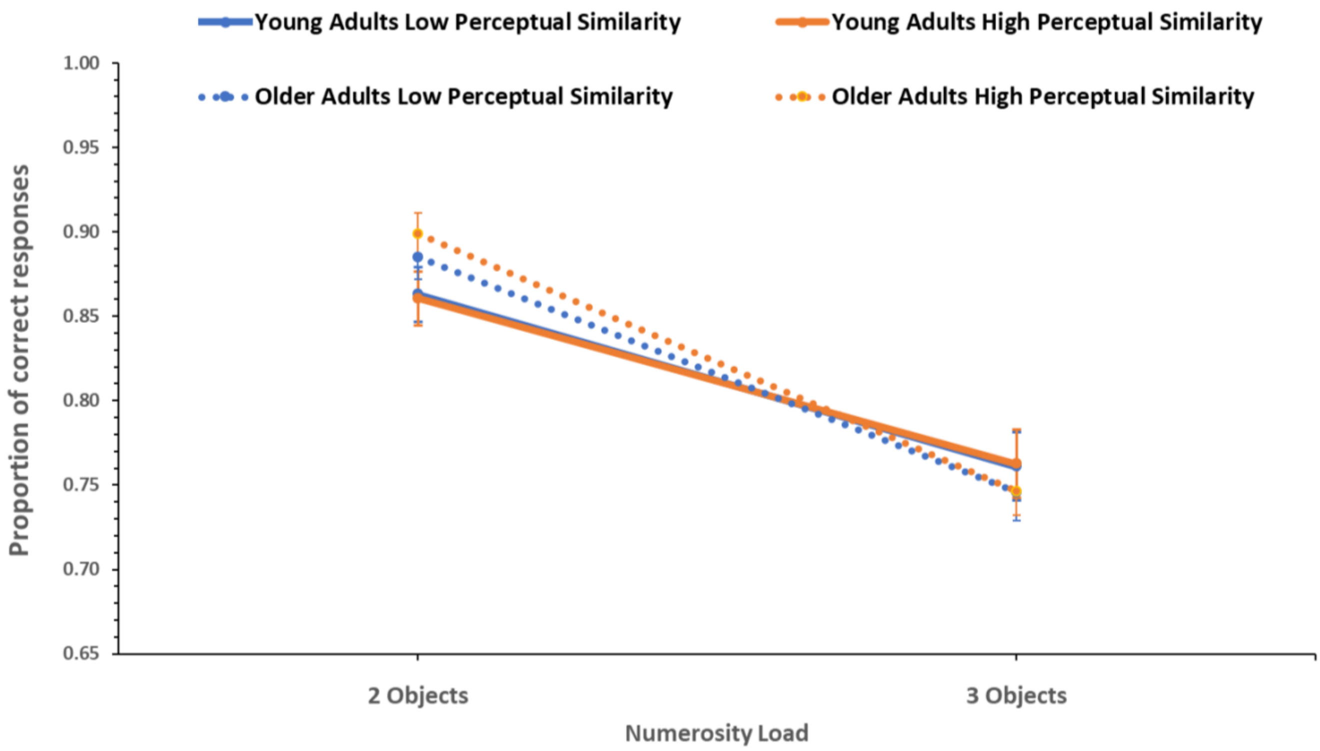
All 32 YAs were used for the final analysis (mean age = 24.91 years, SD = 2.37, 20 female). One of the 32 tested OAs were excluded from the final analysis for being an outlier based on accuracy (outliers were determined in the same manner as in the previous experiment, see 3.2.4). This left 31 OAs for the final analysis (mean age = 68.26 years, SD = 3.42, 19 female). Accuracy analyses were conducted in the same manner as Experiment 1.

3.3.5 Results

The results of the ANOVA with accuracy found no significant effect of similarity, $F(1, 61) = 0.379$, $p = 0.540$, $\eta p2 = .006$, $BF_{10} = 0.143$, or a significant similarity by age group interaction, $F(1, 61) = 0.480$, $p = 0.491$, $\eta p2 = .008$, $BF_{10} = 0.038$, nor a higher interaction between similarity, numerosity or age group, $F(1, 61) = 0.661$, $p = 0.419$, $\eta p2 = .011$, $BF_{10} = 5.303e+43$. There was no significant interaction between similarity and numerosity, $F(1, 61) = 0.201$, $p = 0.656$, $\eta p2 = .003$, $BF_{10} = 1.312e+44$. See Figure *14* for the proportion of correct responses when perceptual similarity was low or high and the numerosity was 2 or 3 for both young and older adults. Additionally, there was no overall between subjects age effect, $F(1, 61) = 0.119$, $p = 0.732$, $\eta p2 = .002$, $BF_{10} = 0.262$.

Figure 14

Young and Older Adults Proportion of Correct Responses in Conditions of High and Low Perceptual Similarity and Numerosity of 2 and 3 in Experiment 2 Change Detection Task



Note. Dotted lines correspond to older adult's (OA) proportion of correct responses, whereas solid lines correspond to young adult's (YA) responses.

There was however a main effect of **Numerosity**, $F(1, 61) = 324.155$, $p < .001$, ηp2 = .842, $BF_{10} = 8.685e+44$. Post hoc comparisons with FDR correction indicated that the set size two conditions and the set size three conditions were significantly different from each other (p<.001). Both OAs and YAs had significantly lower accuracy in the set size three condition compared to the set size two conditions.

A significant interaction was also found between **Numerosity and group**, $F(1, 61) = 11.263$, $p = 0.001$, ηp2 = .156, $BF_{10} = 3.629e+44$. However, post hoc independent samples t-tests with FDR correction indicated the set size 2 condition to not be significantly different between the two age groups (p=0.3164), nor were the set size 3 condition significantly different between the two groups (p=0.5026). Considering the two age groups separately, accuracy performances in set size condition 2 were significantly different than set size 3 for OAs ($p<.001$) and for YAs ($p<.001$).

3.3.6 Experiment 2 Discussion

Similar to Experiment 1, regarding age-effects, here I only found a significant numerosity by age group interaction, but no reliable difference emerged from follow-up analyses. Correspondingly to Experiment 1, I also found a high Bayes Factor, suggesting strong evidence for the alternative hypothesis. This effect was present regardless of the perceptual similarity manipulations. The perceptual similarity condition additionally had no effect on either age groups, in the sense that the high amount of perceptually similar items (color) did not influence performances.

3.4 General Discussion

The main questions addressed in the current study were a) whether the content of object representations influence OA's CDT performances, or whether effects are solely due to the amount presented; and b) whether the typical finding in the aging and vWM field using CDTs in which OAs recall fewer geometrical stimuli, extend when real-world objects are used. To achieve this aim, in two experiments I manipulated the characteristics (through object similarity) between the objects presented in order to explore whether possible detriments in

OA's vWM performances are not only related to the amount of representations, but also interact with the characteristics of the objects.

In both experiments OA and YAs had significantly worse performances in the set size condition 3 compared to the set size 2 condition. OAs demonstrated similar performances compared to YAs, both in terms of the amount of items presented, but also in the influence of the content of the representations.

Considering first the lack of an exacerbated effect in OAs of the number of relevant items presented, this finding is in opposition to previous studies (Jost et al., 2011; Sander et al., 2011) using geometrical stimuli. It is possible the use of real-world objects therefore precipitated the similar age performances. Together with the small amount on the cued side of the display (at maximum three objects), this could have led OAs to maintain each item and successfully respond whether there was a change in the display.

Considering my previous predictions of similarity influence in these CDTs on OA's vWM performances, I interestingly found no influence in aging of the higher similarity conditions, either conceptual or perceptual. This is in opposition to previous findings indicating that OAs were more likely to falsely recognize objects that contained perceptual and conceptual features to objects that had been presented previously (Boutet et al., 2019; Pidgeon & Morcom, 2014). It is possible that given the usage of real-world objects, OAs developed a technique that overrode any influence of the characteristics of the objects presented, to maintain similar performances to YAs. Wiegand and Wolfe (2020) recently implemented a hybrid visual and memory search task in which they also used real-world objects, and once generalized age-related slowing was accounted for, they found no vast differences in OA's performances, compared to YA's performances. The researchers theorized that due to the use of real-world objects, subjects may have benefited from utilizing a strategy through developing semantic associations with the items (Wiegand & Wolfe, 2020). Moreover, it has also been previously demonstrated that OAs are able to utilize attentional control and subsequently benefit from retro-cues in order to circumvent memory precision declines (Mok et al., 2016). Furthermore, in the aforementioned Mitchell et al. (2018) study, investigating OA's precision of colored dot representations, the researchers separated trials in which the target (in which the participant needed to adjust the color accordingly), was presented in the test array along with the other previously presented probe dots from the first memory display (signifying a context aid). These trials were compared with trials in which the target dot to adjust in the test array was presented along with the previously presented dots as gray outlined dots (no context aid; Mitchell et al., 2018). The researchers found OAs were able to use the context of the presentation of the other dots colors as an aid to benefit their performances (Mitchell et al., 2018). Evidently, it is possible in aging that OAs can capitalize on a technique in order to benefit their performances. Accordingly, possibly OAs in the current study were able to utilize a technique in order to maintain similar performances as YAs.

Relatedly, an additionally possible strategy that OAs could have utilized in order to maintain similar performances to YAs would be to utilize the shapes of the objects, as opposed to individually retaining and recalling each object. For example, considering **Figure 13** Panel B, participants could have memorized the object in the upper-left hand corner to be circular, the image in the middle to have individualized upright points (fingers on the glove), and the object in the bottom to be a flatter circular shape. Subsequently, in the test display if one of these shapes violated those characteristics, the participant would have responded that there was a change, regardless of not being able to recall which item changed, or what the object was in the previous display.

An additional possibility is that subjects took a "snapshot" of the entire display of items on the cued side and when the test array violated that snapshot, they were able to respond that there was a change in the display. This technique, also referred to as ensemble representation has been suggested to benefit vWM performances (Alvarez, 2011). The lack of a control for the shape of the objects was a limitation in the current study, and should be controlled for in future studies. A possible method to control for the usage of shape would be to implement a change localization experiment in which one of the items is presented, not the entire group. This would limit the possible strategy of using a snapshot of the ensemble of all of the images together. Alternatively, individually presenting items in individual memory arrays in different positions (Mitchell et al., 2000a).

Chapter 4

Attention and Aging in Visual Search

4.1 Introduction

A cognitive function known to decline throughout the discourse of aging are attention abilities (Naveh-Benjamin & Cowan, 2023). One paradigm for measuring attention is the visual search task (VST), in which an observer must search for a target through different distractors presented in a display (Wolfe, 1994). In VST, the predominant measurement of performance is the observer's reaction times (RTs) to the presence or absence of their target (Wolfe, 2020).

As mentioned previously, earlier findings in the aging field using VST suggest OAs' have more difficulties when there is increased similarity between distractors and the target to find. OAs are known to perform similar to young adults (YAs) when search is "easy", namely when a target is distinguishable and "pops out" in the display amongst distractors that do not share features with the target (Plude & Doussard-Roosevelt, 1989; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). Furthermore, this age-effect is exacerbated with each increased amount of distractors in the display (Plude & Doussard-Roosevelt, 1989). The age-related detriment in search tasks with target-distractor feature similarity has been found in several paradigms using not only colored letters but also oriented lines of varying levels of similarity to the target (Harpur 1991; Scialfa et al., 1998).

Further suggesting an effect in aging when there is increased similarity between objects, Scialfa and Thomas (1994) presented older and young subjects with two stimuli that could vary in color, shape and size and each observer had to respond whether the two stimuli on the given trials were either "same" or "different". Scialfa and Thomas (1994) found in particular that when the stimuli were similar to one another, OA's had more difficulties in correctly responding whether the stimuli were "different", further reinforcing the finding of an enhanced age-related difficulty in performing a task when there is an increased relation between target and distractors. This finding appears to suggest that OAs' have more impairments in distinguishing between shared features. This effect being apparent even in the case in which there are only two items presented (Scialfa & Thomas, 1994). Importantly, it appears that the similarity between presented items seems to always have an effect in aging on performances. Whereas the amount of items might not have an influence unless search is “hard”, and the target does not “pop out” in the display (Plude & Doussard-Roosevelt, 1989).

In a recent experiment using large set sizes (up to 16 real-world objects), Wiegand and Wolfe (2020) conducted three different experiments exploring OA’s performances in detecting a target in a “hybrid search task”, in which both the memory (amount of possible targets that need to be remembered), and visual set size (total amount of objects in a search display) are manipulated (Wolfe, 2012). When generalized age-related slowing was accounted for, the researchers found there were no qualitative performance differences between older and YAs (Wiegand & Wolfe, 2020). In their experiment, the researchers presented a multitude of real-world stimuli, but did not directly manipulate the similarity between the objects presented (Wiegand & Wolfe, 2020). In a sense, although the items did not “pop out” in the same manner as a red letter “X” presented amongst green “O” letters (Plude & Doussard-Roosevelt, 1989), the use of an array containing different real-world objects with no controlled and shared similarity, may have allowed OAs to perform similarly to YAs (Wiegand & Wolfe, 2020). Therefore, the question remains as to whether shared similarity amongst items, then in conjunction with an increased amount of items, are the main precipitators of age effects in search.

Probing this question whilst using a VST and tracking older and YA’s eye movements, Williams et al. (2009) manipulated the similarity of a select set of distractors in a display of 12 real-world objects. In their experiment, each display contained 0-3 targets and the similarity between the remaining distractor objects and the target(s) were manipulated in color (3-4 distractors) or meaning to the target (3-4 additional distractors; Williams et al., 2009). For example, if the target(s) to search for on a particular display was a yellow drill, a color distractor would be another yellow object (a yellow backpack), while a category distractor would be a drill in a different color (a red drill; Williams et al., 2009). Williams et al. (2009) found OAs were slower and less accurate in their search when there were more targets in the display (up to 3 possible targets). An additionally interesting finding coming from the eye movement analysis was that when considering the object type (targets, color or category distractors, or unrelated distractors), OAs viewed the target images for the longest amount of time (in comparison to the other object types), and disproportionately longer than YAs (Williams et al., 2009). Additionally, OAs viewed the category distractor images for the second longest amount of time, and then the color distractors, each object type viewing time disproportionately longer than YAs. These findings appear to suggest that although the age differences in behavioral performances found were not dependent on the similar distractors, there does appear to be differences in how the objects (and in particular, objects of a certain type) were evaluated during search by OAs. OAs may be initially (aside from targets) more distracted by the meaning (category distractors) of the objects, compared to color distractors (Williams et al., 2009). However, possibly due to the fact there was a small amount of these similar object types individually in each display (up to three only color or up to three only categorically-related), OAs may be able to override these differences, after visually evaluating these objects (Williams et al., 2009).

Current Study

The main objective of the current study was to examine whether increasing the relationship between target and distractors, in conjunction with increasing the amount of real-world objects, precipitates age-related effects in visual search. I consolidated this question in the present study into one paradigm and investigated it throughout two different experiments. The implementation of using real-world objects was important due to the majority of earlier

VS studies utilizing geometrical stimuli. Moreover, there has been a shift in the YA research field to implement more real-world stimuli (Asp et al., 2021; Brady et al., 2016), further suggesting the importance of implementing these stimuli in aging research as well.

I tested two groups of OAs and YAs in a VST in which both the relation between one target and a varied amount of distractor objects in the display was manipulated across two levels of similarity: perceptual (color similarity) and conceptual (categorical similarity). My manipulation of similarity was different from Williams et al. (2009) as the similarity in the current study was controlled for across all items in the display, not mixed (including both conceptual and perceptual distractors in each display) as was done in the prior. For example, in the current study, one trial would contain perceptually similar distractors in relation to the target, while another trial would contain conceptually similar distractors, as well as a separate trial type of a baseline condition (no similarity). Alternatively, in Williams et al. (2009), each trial would contain 3-4 conceptual distractors, 3-4 perceptual distractors, and so forth. The motivation of manipulating similarity in the manner done in the present experiment was two-fold: first, to isolate the two types of similarity and individually investigate whether age-related impairments arose, and second, to see the possible interaction of type of similarity and the amount of these type of distractor objects – a seemingly important determinant of OA's performances in VSTs (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998). Accordingly, the total amount of objects was manipulated in the display as well: 5, 7 and 10 objects (Experiment 3) and 10, 12 and 15 objects (Experiment 4). Additionally, of interest to note when considering my similarity manipulation in the present study, is a field of research that theorizes a decreased ability in aging in distinguishing between overlapping features: perceptually and semantically (see Deng et al., 2021; Gellersen et al., 2023, however see Jingling & Lai, 2022). Accordingly, my present manipulation of similarity could better explore whether perceptually or conceptually similar objects disproportionately influence OA's visual search behaviors, which may possibly be the result of a reduced ability to distinguish objects when they contain overlapping features.

Key predictions for this study are that OAs will demonstrate more difficulties in comparison to YAs in the higher set sizes and this will interact with the two similarity conditions, perceptual and conceptual similarity. This is based on previous findings discussed above in which increased similarity between items led to worse performances in aging (Scialfa & Thomas, 1994), an effect that was exacerbated with more items in the display (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998). Concerning the different types of similarity manipulations; perceptual and conceptual, it is hypothesized that the perceptual condition will have the largest effect on OA's performances, compared to the conceptual condition, as perceptual similarity has been the type of similarity found to lead to aforementioned age impairments in search (in color, shapes and lines; Plude & Doussard-Roosevelt, 1989; Scialfa & Thomas, 1994; Scialfa et al., 1998). However, it will be an interesting investigation to see whether these effects extend to the conceptual similarity dimension. It is possible based on previous findings (see Koutstaal et al., 2003) that conceptual similarity leads to a detriment in visual search for OAs as well.

Experiment 3: Visual Search Task with 5, 7 and 10 Objects

4.2 Experiment 3 Methods

In Experiment 3, I tested older and young adults' in an online visual search task in which participants were asked to report whether a target was present or absent. In each trial, there was a varying number of distracting objects that were either similar (perceptually or conceptually similar) to the target presented at the start of each block or had no fixed similarity with the target, signifying a baseline condition. In addition to similarity type, the second main manipulation for this experiment was set size, therefore each trial included either 5, 7 or 10 objects in total. With this experimental design, I was able to examine set size by similarity effects and whether this interacted with age group in determining visual search performances.

4.2.1 Participants

All participants were recruited online through Prolific (www.prolific.co). I aimed for 30 participants in both age groups. All participants could only take part in the study using a Desktop computer (no mobile phone or tablet) and were recruited from Prolific's option of "All countries available" as well as from a "Standard sample" which allows for the study to be distributed to all available participants with the only restrictions being the other experimental criteria explained below.

Participants for both age groups were recruited from a previous sample from another study within our group (Tagliabue et al., 2022a; Tagliabue et al., 2023). The reasoning for this was to ensure the cognitive health of the OA sample (aside from the Prolific screening), as all of these OAs had a cognitive screening score from SATURN of 26 or above, indicating cognitive healthiness (Bissig et al., 2020). For older adults (OAs), in addition to the inclusionary criteria of never having been diagnosed with mild cognitive impairment (MCI) or dementia, the additional criteria were that participants must be between 65 and 75 years old, fluent in English, have normal or corrected-to-normal vision and were right-handed or ambidextrous. For young adults (YAs), I set the inclusionary criteria that participants must be between 20 and 30 years old, must be fluent in English, right-handed or ambidextrous and have normal or corrected-to-normal vision in order to be eligible to take part in the study.

After removing outliers (see 4.2.4 below), there were 25 YAs for the final analysis (mean age = 24.72 years, SD = 2.84, 10 female) and 28 OAs for the final analysis (mean age = 69.43 years, SD = 3.36, 14 female).

All participants received a monetary reimbursement of 8 sterling pounds per hour. After agreeing to take part in the experiment in Prolific, participants were all passed on to Psytoolkit (psytoolkit.org) to give their informed consent. The study was approved by the Università degli Studi di Trento Research Ethics Committee (Protocol No: 2020-021).

4.2.2 Stimuli and Apparatus

All stimuli were downloaded from the online repository of Aude Oliva Lab at MIT (http://olivalab.mit.edu/MM/index.html). The object images used in this study were collected from the "Object Categories" repository (cited in Konkle, Brady, Alvarez and Oliva, 2010). Each of the 72 image objects that I used were edited in Adobe Photoshop into the following four-color groups: 1) black (RGB: 0, 0, 0), 2) blue (RGB: 13, 69, 100), 3) brown (RGB: 104, 53, 2), and 4) green (RGB: 4, 77, 48). As some of the stimuli images were light-colored objects originally (white pants, for example), the tonal values were changed after adding the color codes. The same images used in this experiment were those used in Experiment 2, see Appendix B for more details.

Each of the 72 objects were also divided into four main object categories: 1) Tools / Appliances, 2) Furniture, 3) Cook / Tableware and 4) Clothing. The images determined to belong to each of these categories were predetermined through a series of previously conducted pilot studies on a separate group of participants in the same age ranges for older (65-75 years old) and young adults (20-30 years old).

Objects were 3 x 3 cm and were presented within a 4-quadrant display, each presented with a 0.30-degree jitter on a blank white screen (RGB: 255, 255, 255) with a black fixation cross (RGB: 0, 0, 0) in the center of the screen. In order to ensure that in this online experiment, each object was presented at the same pixel resolution according to the participant's computer dimensions, an additional step to the set-up of the experimental procedure included a "credit card slider" (Li, Joo, Yeatman, & Reinecke, 2020 and https://gitlab.pavlovia.org/Wake/screenscale). The purpose of this slider is to calculate the size of the participant's computer screen. For this implementation, participants were first asked to sit at an arm's length distance from the computer and were presented on their screen with a virtual credit card and instructed to hold a physical bank card to the screen and adjust the virtual card to be the same size as their physical card. Based on these provided dimensions, a calculation is then used by the program to determine the size of the participant's screen as well as the pixels per centimeter (cm) of their computer.

4.2.3 Design and Procedure

After completing the initial recruitment in Prolific, participants provided their written informed consent on Psytoolkit (psytoolkit.org; Stoet, 2010, 2017) . Here, the participants were asked again screening questions, in order to confirm the validity of the information given in Prolific. In short, the participants were asked their age, whether they had normal or corrected-to-normal vision, if they were fluent in English. OAs were additionally asked whether they had ever been diagnosed with MCI or dementia. If any of the answers corresponding to vision, English fluency or MCI / dementia given during this screening did not correspond to the information given during the Prolific recruitment, the participant would be told they could not take part in the study because of the mis-match and were returned back to Prolific.

Participants eligible to take part in the study were then asked general demographic questions, including gender (with the available option of "Prefer not to say"), level of education, years of formal education and hours of sleep that they had the previous night. Demographic general information including age, gender and years of education is listed in **Table *3***.

After the demographic questions, participants were then shown the Information Sheet as well as the final consent guidelines and provided their informed consent by clicking a button "YES, I consent" and proceeded to the main experiment. The main experiment was created in Psychopy® (v2020.2.10; Peirce et al., 2019), with MATLAB and JavaScript code and hosted through Pavlovia (Pavlovia.org, Pavlovia Surveys; Open Science Tools, Nottingham, UK).

Table 3

General demographics for participants in the Experiment 3 Visual Search Task with 5, 7 and 10 Objects

	Young adults	Older adults
	n = 25	n = 28
Age	m = 24.72 yrs. SD = 2.84	m = 69.43 yrs. SD = 3.36
Gender		
Female	10	14
Male	15	14
Years of education	m = 15.76 yrs. SD = 3.11	m = 15.41[a] yrs. SD = 3.70

Note. Demographic information includes final sample analyzed after excluding outliers.

[a] One of the 28 Older adult subjects did not respond to this question.

yrs.= years

m = mean

SD = standard deviation

The experiment started with adjusting the stimuli dimensions depending on the participants' monitor size (see Li et al., 2020), and continued with the instructions for the main task. Participants were told that in different blocks they would be presented with an object in the center of the screen that was the target for a specific block. Additionally, they were instructed that they would be presented with different arrays in which the target object may or may not be presented amongst other objects, and they will need to respond on their keyboard for the presence or absence of the target object (keyboard button "c" if their target object is present in the array or "m" if it is missing). Participants were also told to keep their eyes fixated on the center fixation cross that would remain on screen throughout the experiment. Participants were given visual examples of both types of conditions (target present and absent conditions) and were not told of the similarity between objects that would occur in the different arrays of the experiment. Participants started the experiment with 18 practice trials.

During the first nine practice trials, the fixation cross in the center of the screen turned red when the participants needed to respond (during a 3 second response screen). The following nine practice trials replicated the main experiment in which the fixation cross would remain black, replicating the actual task. Participants were given feedback whether they had responded correctly or incorrectly throughout the practice trials after responding. Additionally, the target object during the practice trials was never a target object during the actual experiment.

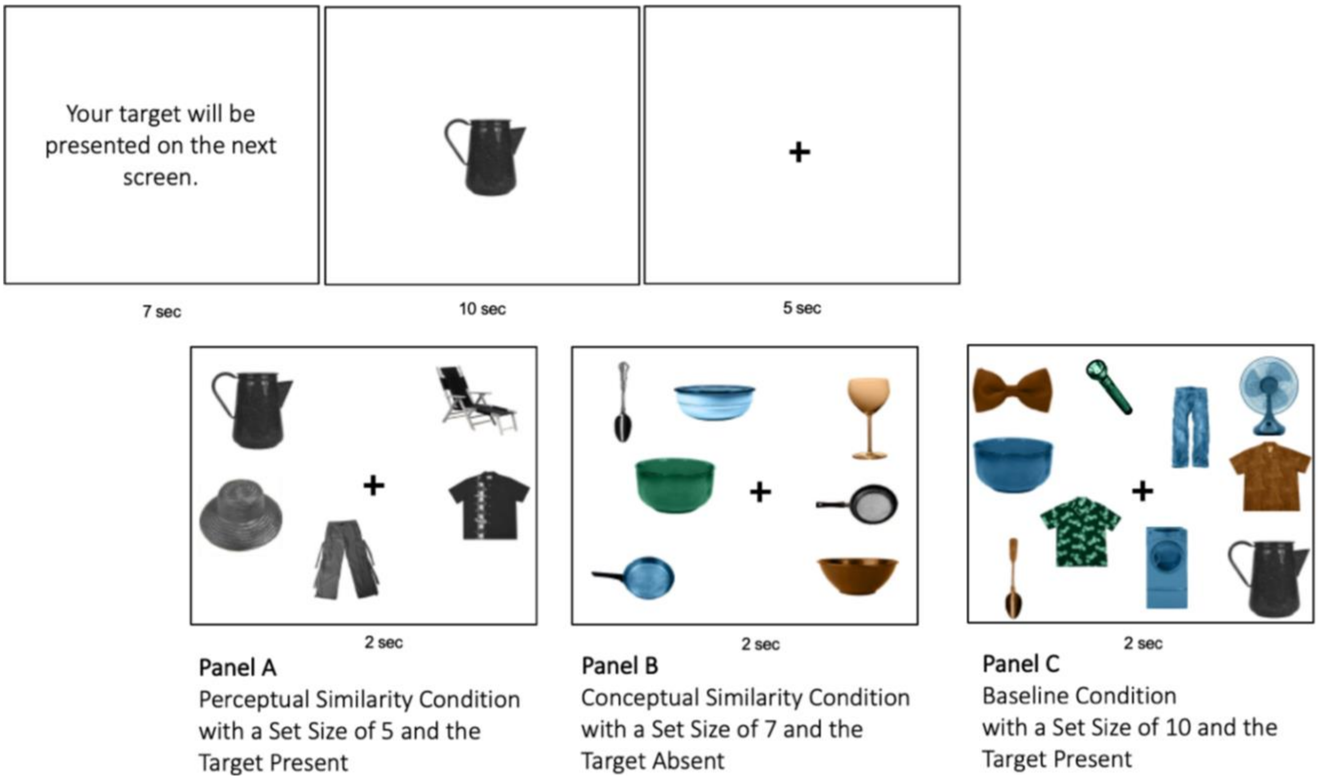
During the experiment, each participant was presented with a total of eight blocks and therefore eight target objects. Each participant received a randomized set of trial files, so that not all participants had the same eight target objects. Additionally, all eight targets across the duration of the full experiment for each participant were counterbalanced, ensuring that everyone would have each of the four colors presented as a target object two times (in two different blocks) and each of the four categories presented as a target two times as well. The same combination of color and category for a target was never presented to the same participant twice. For example, if a black (color), tool / appliance (category) object was a target in one block for participant 1, the same participant when presented in a different block with another tool / appliance object, that object would not be black (and instead: blue, brown, or green).

At the start of each block, the following text was presented for 7 seconds: "Your target will be presented on the next screen." (see Figure *15*). The next screen then showed the target object for 10 seconds. In Figure *15* the target object is a black pitcher (belonging to the Cook / Tableware category). After this, a blank white screen with a black fixation cross in the center was presented for 5 seconds before an array of objects (either 5, 7 or 10) were presented for 2 seconds. Participants could respond on their keyboard during this 2 second image display whether the target was present or absent in the array, as well as during an additional 3 second response screen containing only a blank screen with fixation cross. Immediately after responding (either during the 2 second image display or during the 3 second response display), the participant continued to the next array. Inter-trial interval was 1 second. There were 99 total trials in a block, with nine of those trials being "catch trials". Catch trials included trials in which the same exemplar type (not the exact image, however), would be presented in both target present and target absent conditions (for example if the target was an axe, another axe would be presented). In total, across the whole experiment, there were 792 trials. Participants were given the option every 50 trials to take a break throughout the experiment if needed.

Within each block, each manipulation was randomized across the different arrays. The main manipulations included 1) Similarity Type (3 levels): perceptual similarity, conceptual similarity, baseline; 2) Set Size (3 levels): 5, 7 or 10 objects and 3) Target Presence (2 levels): present or absent. The perceptual similarity condition included distractor objects that were the same color as the target (see Figure 15 Panel A). The category of the distractor objects was randomized, allowing the possibility that some of the distractors could be from the same category as the target, as I did not want the target to “pop out” in the display as a singleton (Treisman & Gelade, 1980). The conceptual similarity condition (see Figure 15 Panel B) included distractors that were the same category as the target. In alignment with the parameters set for the perceptual similarity condition, the distractors in the conceptual similarity condition were also randomized in their color, allowing for some distractors to be the same color as the target. Finally, in the baseline condition (Figure 15 Panel C), distractors were randomized in both color and category with relation to the target, allowing also for the same color or category as the target to be presented. Figure 15 Panel B is an example of a target absent condition, whereas Panel A and Panel C (Figure 15) are target present conditions.

Figure 15

Visual Search Task with 5, 7 and 10 Objects Experiment Example



Note. Images not to scale.

Sec: Seconds

For target absent conditions (Figure 15: Panel B), instead of the target for that block being presented in the display, another image that was the same color and category as the target for that block was included along with the other objects in the display. Important to note, aside from the small portion of catch trials, the same exemplar type of target and a distractor would not be presented in the display, neither in target present or absent conditions. For example, if the target was an axe, a distractor would not be a different axe. The same exemplar type of distractor could be presented more than once however.

After completing the experiment, participants were transferred from the experiment to an exploratory survey designed in Psytoolkit, regarding their knowledge of the manipulations, and also possible strategy usage. As this survey was explorative, the responses will not be described here, but are available upon request. After completing the survey, participants were then returned back to Prolific with a completion code. For the full procedure of the study (consent, experiment and survey) YAs took on average 55 minutes while OAs took on average 45 minutes.

4.2.4 Data analysis

One YA returned their submission; data from four YAs were excluded for being outliers based on reaction times (RTs) or errors being outside of the norm for their age group.

Outliers were determined in the same manner as in Chapter 3, through using the Inter-Quartile Range (IQR) method calculated in Excel (Rousseeuw & Croux, 1993; Yang et al., 2019). In the IQR method, a normal data range is calculated based on all participant's averages and those who have responses above or below this normal range are determined to be outliers (Rousseeuw & Croux, 1993; Yang et al., 2019). This left 25 YAs for the final analysis (mean age = 24.72 years, SD = 2.84, 10 female). Two OAs were excluded from the final analyses for being outliers (calculated with the same Inter-Quartile method as for the YAs). After removing the outliers, there were 28 OAs for the final analysis (mean age = 69.43 years, SD = 3.36, 14 female).

To investigate the performance of both age groups, repeated measures ANOVAs were conducted in JASP (http://www.jasp-stats.org) with the between-subjects factor of age group (OA, YA) and the within-subjects factors of Similarity Condition (perceptual, conceptual, baseline), Set Size (5, 7, 10) and Target Presence (present, absent). Greenhouse-Geiser corrections were used when appropriate. Additionally, Bayesian statistic ANOVAs were conducted using JASP (Van Den Bergh et al., 2020). Bayes Factor 10 (BF_{10}) is reported which is the likelihood of the alternative model compared to the null model, and this BF_{10} value is reported following the results of the corresponding ANOVA results. Bayes Factor values above 1 is considered as support for the alternative hypothesis, while a Bayes Factor value less than 1 is considered as support for the null hypothesis. Significant interactions were further investigated either with independent samples t-tests to investigate comparisons between groups, or paired samples t-tests to disentangle results within-groups, all with false discovery rate corrections applied (FDR; Benjamini & Hochberg, 1995). RT, proportion correct, error rates as well as Post hoc T-tests and FDR corrections (Groppe, 2023) were all calculated or performed in MATLAB.

The measure used for statistical analyses were Balance Integration Scores (BIS; Liesefeld & Janczyk, 2022), which were calculated due to a speed accuracy tradeoff found for this experiment (Liesefeld & Janczyk, 2019) for YAs. Balance Integration Scores (BIS) are a useful analysis in order to account for SATs through combining both RTs and proportion of correct (PC) responses (Liesefeld & Janczyk, 2022). In order to calculate BIS in the current experiment, the average proportion correct (PC) in each condition were determined for both YAs and OAs. The total mean of all subject's PC values was subtracted from the PC value for each subject in each condition, and then each of these values were divided by the total SD of all PC values. For example, if a participant had a proportion correct value of .90 in condition 1 (baseline set size 5 target absent), and the overall participants proportion correct mean was 0.97 with a standard deviation of 0.04, the overall mean of 0.97 would be subtracted from the participant's condition 1 value of 0.90 and divided by the SD value of 0.04. This calculation resulted in a zPC value for participant 1 in condition 1 of -1.54.

This procedure then resulted in a zPC value for each subject in each condition. The same process was then applied to RT values: the total mean of all RTs was subtracted from each RT value for the subjects in each condition, and then each of these values were also divided by the total SD of all RT values, resulting in a zRT value for each subject in each condition. Finally, each subject's conditional zRT value was subtracted from the according zPC value, resulting in a BIS value for each subject in each of the conditions. For interpreting BIS, a value above 0 indicates above average performances, whereas below 0 is an indication of below average performances (Liesefeld & Janczyk, 2022). Important to note, I also conducted more traditional visual search analyses (slopes), however I found no significant age interactions with similarity condition, therefore the analyses presented here will be focused on BIS. Please refer to Appendix C for Experiment 3 slope analysis results.

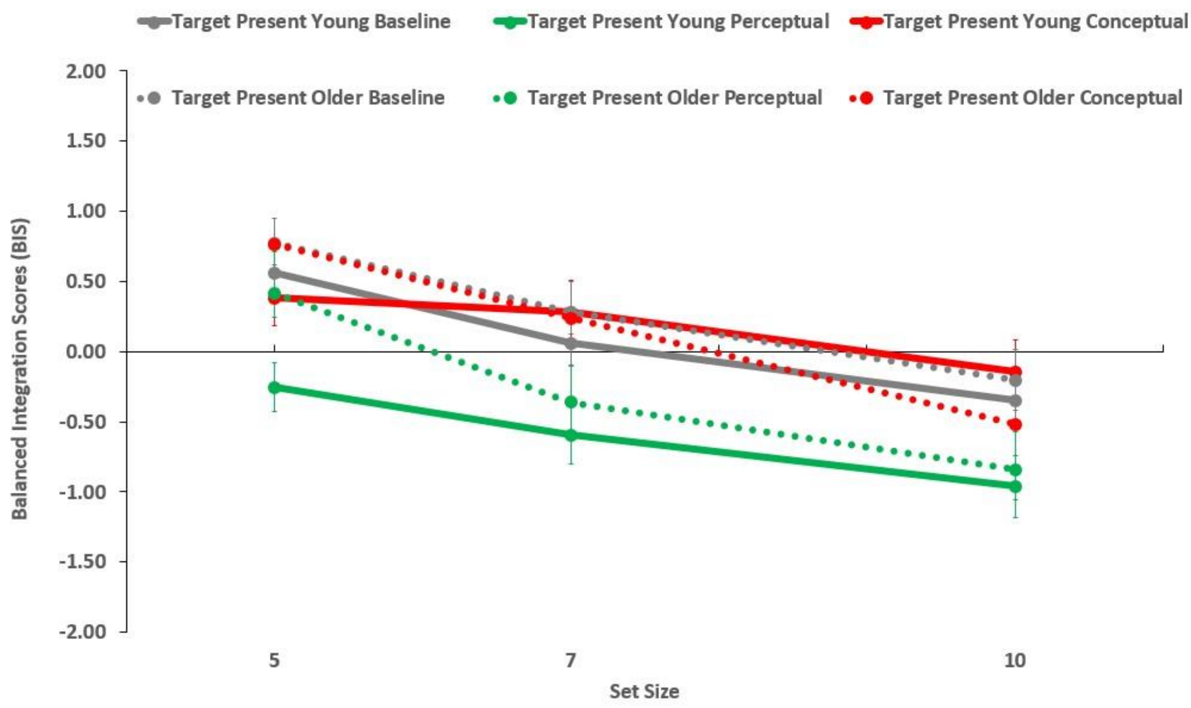
4.2.5 Results

The ANOVA with BIS indicated a significant effect of **similarity** condition, $F(2, 204) = 102.457$, $p < .001$, $\eta p2 = 0.668$, $BF_{10} = 1.312e+21$. Post-hoc comparisons with FDR correction demonstrated the perceptual similarity condition to be significantly different from the baseline and conceptual similarity conditions (both: p<.001). Both OAs and YAs had worse performance in the perceptual similarity conditions, relative to the other two similarity conditions. See Figure *16* for mean BIS plotted for young adults and older adults, with panel A depicting target present conditions for both age groups and panel B depicting target absent conditions for both age groups.

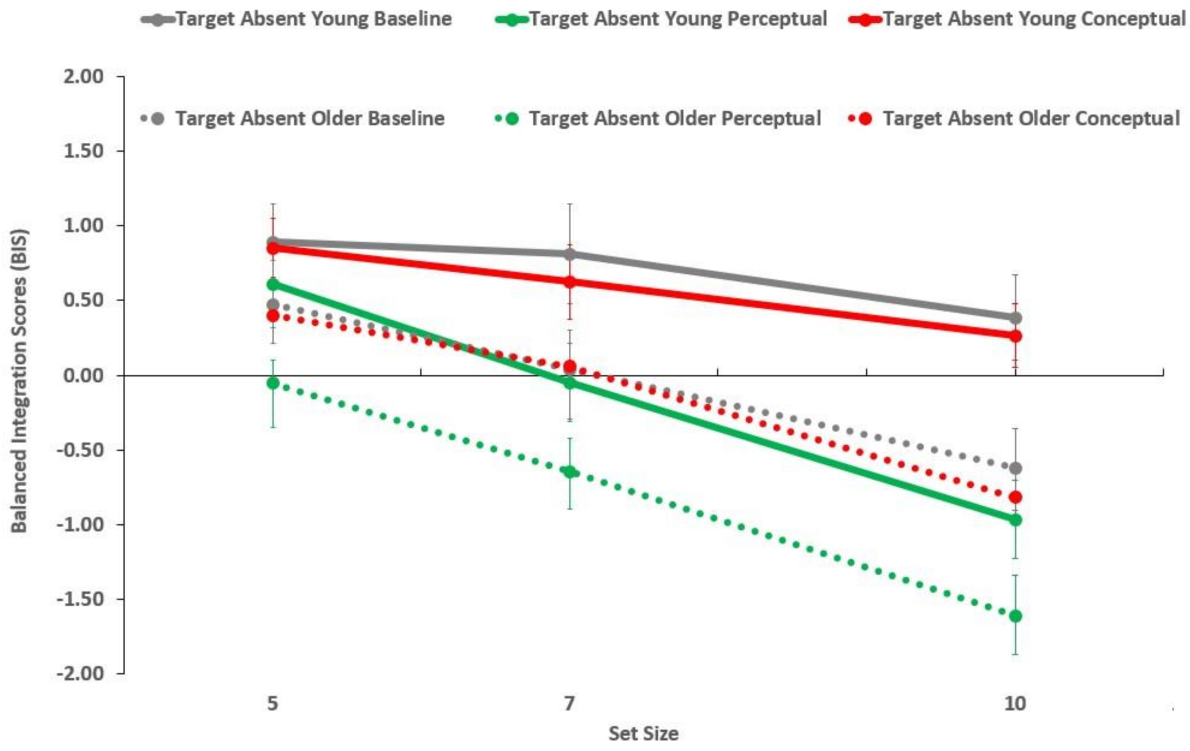
Figure 16

Young and Older Adults Balanced Integration Scores in Visual Search Task with 5, 7 and 10 objects

Panel A



Panel B



Note. Dotted lines correspond to older adults' responses, whereas solid lines correspond to young adults' responses.

I will focus this section on describing the age effects explored in this study. The interaction between similarity condition and age group and the three-way interaction between similarity condition, set size and age group significant were not significant, $F(2, 204) = 1.875$, $p = 0.159$, $\eta p2 = 0.035$, $BF_{10} = 6.064e+20$ and $F(4, 204) = 1.043$, $p = 0.386$, $\eta p2 = 0.020$, $BF_{10} = 9.849e+68$, respectively. Additionally, there was no significant age effect, $F(1, 51) = 1.528$, $p = 0.222$, $\eta p2 = 0.029$, $BF_{10} = 0.434$.

There was a significant interaction between **set size and age group**, $F(1.787, 192.435) = 7.260$, $p = .002$, $\eta p2 = 0.125$, $BF_{10} = 3.231e+41$. However, post hoc independent samples t-tests with FDR correction indicated that there were no significant age group differences in performances for any of the 3 set size conditions, 5 (p = 0.8218), 7 (p = 0.3712) or 10 (p =

0.1517). A paired samples t-tests with FDR correction within each age group found for YAs performances when the set size was 5 to be significantly different than when the set size was 7, and the same for the set size change from 7 to 10 objects (both: p<.001). The same was indicated for OAs at each set size comparison as well (both: p<.001). In Figure *16* it is evident for both age groups the decrease in performances (steadily decreasing to below average performances) with the higher set sizes.

The interaction between **age group and target presence** was significant, $F(1, 51) = 21.381$, $p<.001$, $\eta p2 = 0.295$, $BF_{10} = 0.036$. Post hoc comparisons with FDR correction indicated that YA and OAs were significantly different from each other in target absent conditions (p=0.0043), but not significantly different from each other in target present conditions (p=0.4792). The three-way interactions between similarity, target presence and age group and set size, target presence and age group were not significant, $F(2, 204) = 0.671$, $p = 0.514$, $\eta p2 = 0.013$, $BF_{10} = 5.156e+19$ and $F(2, 204) = 0.201$, $p = 0.818$, $\eta p2 = 0.004$, $BF_{10} = 2.900e+40$ respectively, nor was the four-way interaction between similarity condition, set size, target presence and age group, $F(4, 204) = 1.356$, $p = .251$, $\eta p2 = 0.026$, $BF_{10} = 9.233e+67$.

4.2.6 Experiment 3 Discussion

The results of the repeated measures ANOVA with BIS suggest that while both young and older adults are influenced by the perceptual similarity conditions, this is not enhanced by aging. Although considering the Bayes Factor results, this analysis suggests strong evidence in favor of the alternative hypothesis. Additionally, there were significant age effects in target absent conditions, with OAs performing worse in these conditions. A possibility is that OAs may take longer to confirm the object is absent from the display, this enhanced age interaction in response times with target absence for OAs is a result that has been extensively found in the aging and VS research field (Scialfa et al., 1998).

Despite the lack of a significant interaction between age group and set size for BIS following the post hoc analyses, it is clear in Figure 16 that OAs start with performances all above average at the set size of 5, with a steady decline below the average for set sizes 7 and then 10. Alternatively, YAs (Figure 16) maintain performances above average at set size 5 as well as in the set size 7 and 10 conditions for the conceptual similarity and baseline conditions. Moreover, the Bayes Factor analysis also appears to reflect strong evidence in favor of the alternative hypothesis for this interaction. This appears to suggest the higher set size conditions to start to have an enhanced detrimental impact on OAs. It is accordingly of interest whether an increased amount of objects (above those used in this experiment), precipitate age-related deficits in completing the task to the same level as YAs. Accordingly, in the next experiment, the amount of objects presented to a new set of OA and YAs was increased to 10, 12 and 15 objects.

Please refer to Appendix C for a description of the accuracy, RT and slope results for Experiment 3. In brief, the results of the RT analyses found all similarity conditions to be significantly different for both age groups, and no significant similarity by age group interaction. There was a significant set size by age group interaction in RTs for each of the three (5, 7 and 10) set size conditions, with OAs demonstrating longer RTs. There was also a significant interaction between target presence for each of the set size conditions between the age groups. Furthermore, accuracy analyses indicated a higher accuracy in the baseline and conceptual similarity conditions, compared to the perceptual conditions, for both age groups. There was a significant interaction between age group and target presence with YAs demonstrating a higher amount of errors compared to OAs, both when the target was present and absent. Slopes analysis on RTs indicated each of the three similarity conditions were significantly different. There was also a significant difference in slopes between the two age groups both when the target was present and absent.

Experiment 4: Visual Search Task with 10, 12 and 15 Objects

The aim of this experiment was to explore whether more cluttered displays may exacerbate OAs abilities to perform the VST (concerning both the amount of objects presented and the influence of the similarity conditions on performances). Accordingly, for this experiment, I presented a new set of OA and YAs with the same VST, with the only amendment being the amount of objects presented: 10, 12 and 15 objects. To anticipate, since no speed-accuracy trade off was found in this experiment, only accuracy and reaction times analyses will be reported.

4.3 Experiment 4 Methods

4.3.1 Participants

Recruitment for Experiment 4 was the same as Experiment 3 (the only adjustment was that the monetary reimbursement was decreased to 7.20 sterling pounds an hour). I aimed for 30 participants in each group. Twenty-eight YAs and 30 OAs completed and returned the experiment. After calculating for possible outliers, all twenty-eight YAs were eligible to be used for the final analysis (mean = 25.71 years, SD = 2.58, 19 female). Five OAs were excluded from the final analysis for being outliers (see 4.3.4 below), which left 25 OAs for the final analysis (mean = 68.68 years, SD = 2.66, 15 female). Demographic general information including age, gender and education is listed in **Table *4***.

4.3.2 Stimuli and Apparatus

The stimuli used in Experiment 4 were the same as in Experiment 3 (see 4.2.2). Additionally, objects were 3 x 3 cm and also presented within a 4-quadrant display, each with a 0.30-degree jitter on a blank white screen and with a black fixation cross in the center of the screen. The configuration requirements for Experiment 4 were the same as in Experiment 3.

4.3.3 Design and Procedure

The design and procedure of Experiment 4 also replicated those of Experiment 3, but for the manipulation of set size (here 10, 12 and 15 objects). See Figure *17* for an example of Experiment 4.

Table 4

General demographics for participants in the Experiment 4 Visual Search Task with 10, 12 and 15 Objects

	Young adults	Older adults
	n = 28	n = 25
Age	m = 25.71 yrs. SD = 2.58	m = 68.68 yrs. SD = 2.66
Gender		
Female	19	15
Male	9	10
Years of education	m = 16.79 yrs.	m = 14.40 yrs.

	SD = 2.69	SD = 3.04

Note. Demographic information includes final sample analyzed after excluding outliers.

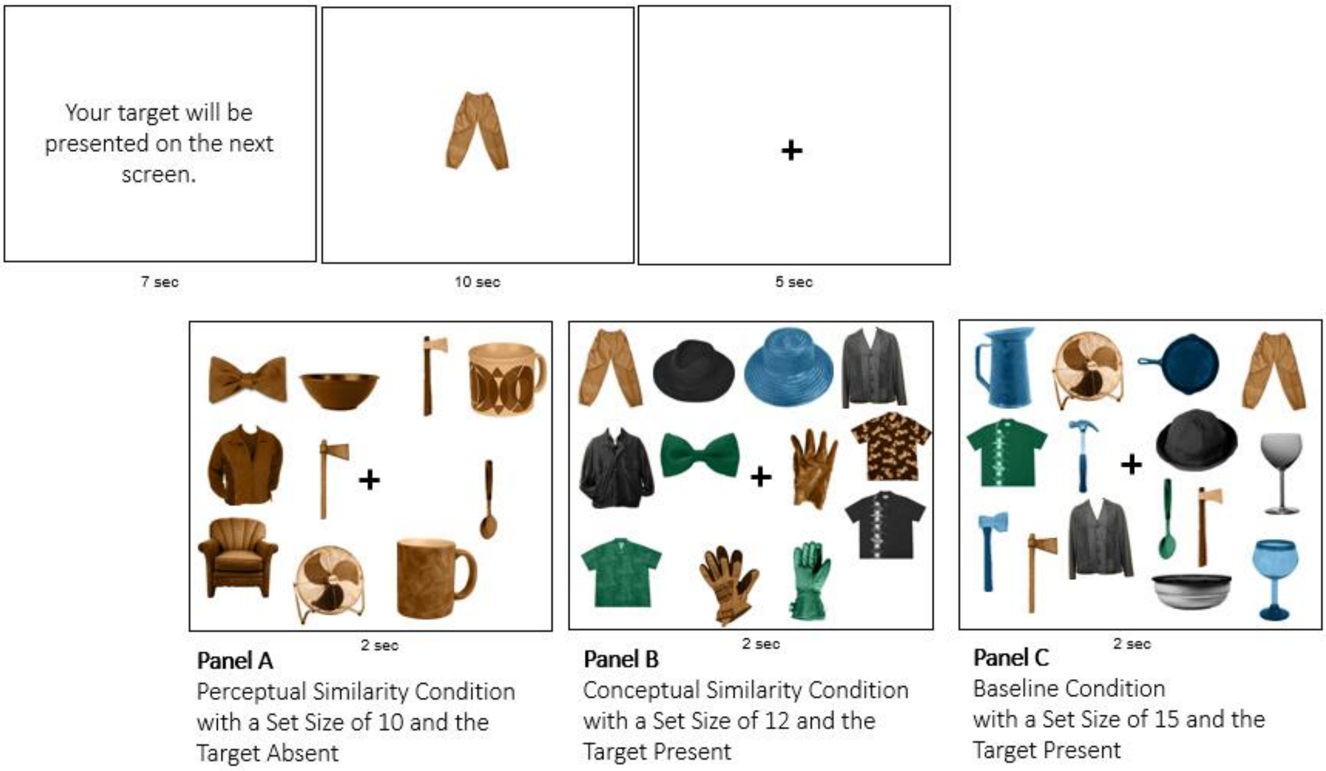
yrs. = years

m = mean

SD = standard deviation

Figure 17

Visual Search Task with 10, 12 and 15 Objects Experiment Example



Note. Images not to scale.

Sec: Seconds

For the full Experiment 4 procedure (consent, experiment and survey), both YAs and OAs took on average 49 minutes.

4.3.4 Data analysis

Twenty-eight YAs and 30 OAs completed and returned the experiment. All twenty-eight YAs were used for the final analysis (mean age = 25.71 years, SD = 2.58, 19 female). Five OAs were excluded from the final analysis for being outliers, leaving 25 OAs for the final analysis (mean age = 68.68 years, SD = 2.66, 15 female). Outliers were determined using the same Inter Quartile calculations as in Experiment 3 (see section 4.2.4).

The statistical analysis was conducted as in Experiment 3. In comparison to the first experiment, a speed accuracy tradeoff was not found in Experiment 4; therefore, RTs and error rates will be presented. Greenhouse-Geiser corrections were used when applicable.

4.3.5 Results

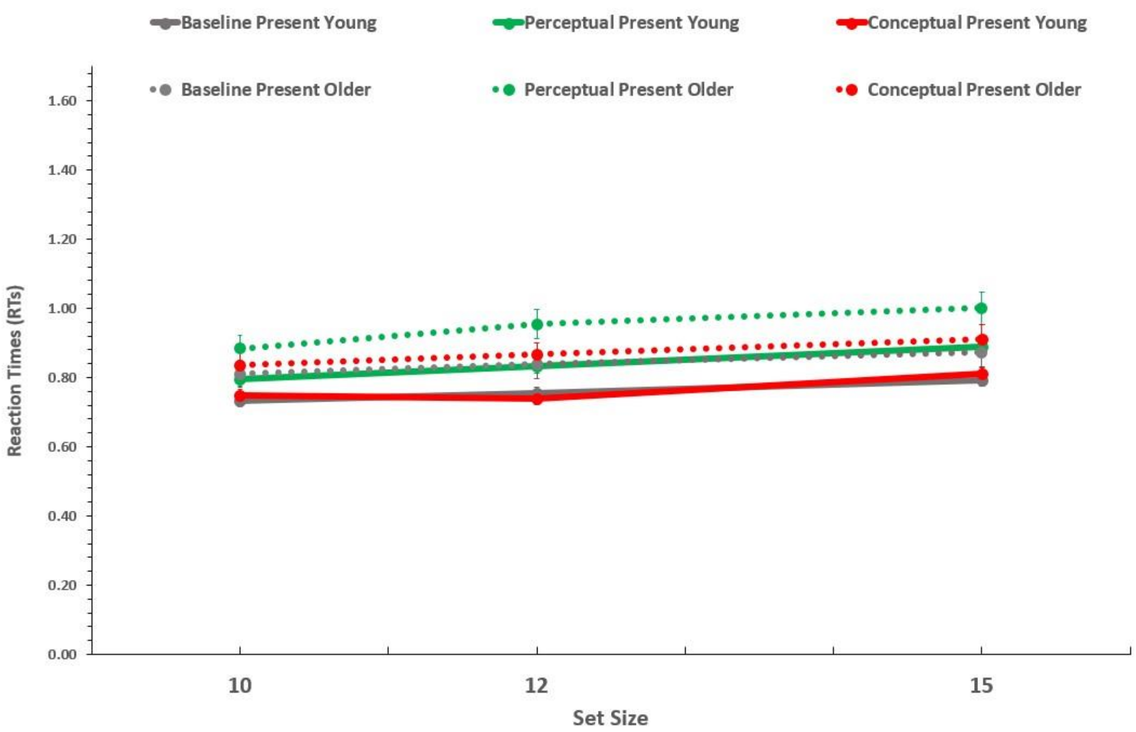
Reaction Times

The repeated measures ANOVA on mean reaction times (RT) for correct responses found an effect of **similarity condition**, $F(1.495, 177.431) = 196.910$, $p < .001$, $\eta p2 = 0.794$, $BF_{10} = 1.789e+36$. Post hoc comparisons with FDR correction demonstrated the perceptual similarity condition to be significantly different from the baseline and conceptual similarity conditions (both: p<.001). Both OAs and YAs had worse performances in the perceptual similarity conditions, relative to the other two similarity conditions. The conceptual similarity condition was also significantly different from the baseline condition with FDR post hoc corrections (both: p<.001). See Figure 18 for mean RTs plotted for young adults and older adults.

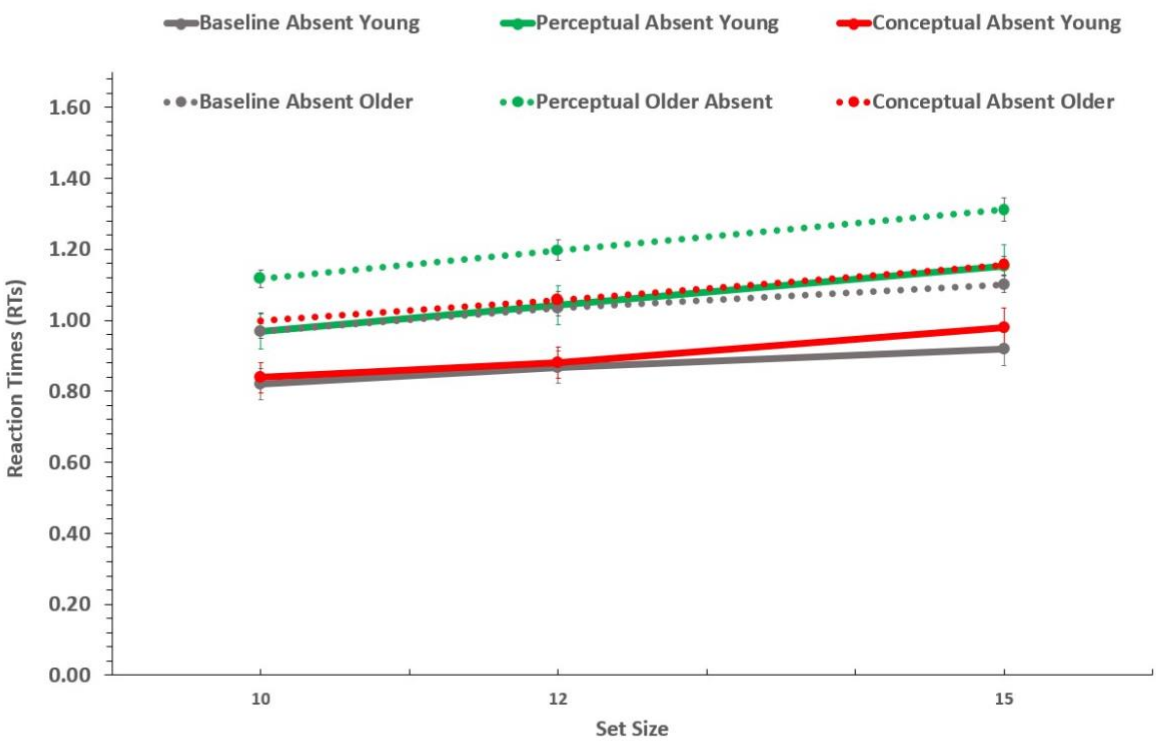
Figure 18

Young and Older Adults Uncorrected Reaction Times in Visual Search Task with 10, 12 and 15 objects

Panel A



Panel B



Note. Dotted lines correspond to older adults' responses, whereas solid lines correspond to young adults' responses.

Measurement is in seconds.

I will focus this section on describing the age effects explored in this study. The interaction between similarity condition and age group was not significant, $F(1.495, 177.431) = 0.452$, $p = 0.581$, $\eta p2 = 0.009$, $BF_{10} = 8.803e+36$. The three-way interaction between similarity condition, set size and age group was not significant either, $F(4, 204) = 0.327$, $p = 0.859$, $\eta p2 = 0.006$, $BF_{10} = 5.495e+63$, nor was similarity, set size, target presence and age group, $F(4, 204) = 0.960$, $p = 0.430$, $\eta p2 = 0.018$, $BF_{10} = 1.903e+251$. There was no significant interaction between set size and age group, $F(1.521, 177.431) = 1.936$, $p = 0.161$, $\eta p2 = 0.037$,

BF_{10} = 9.599e+21, nor set size, target presence and age group, $F(1.518, 177.431) = 1.695$, p = 0.196, ηp2 = 0.032, BF_{10} = 4.211e+153.

There was an overall between subjects **age** effect, $F(1, 51) = 7.035$, $p = 0.011$, ηp2 = 0.121, BF_{10} = 4.979. The interaction between **age group and target presence** was also significant, $F(1, 204) = 9.511$, $p = .003$, ηp2 = 0.157, BF_{10} = 6.790e+111. Post hoc comparisons with FDR correction indicated that YA and OAs were significantly different from each other in both target present conditions (p=0.0337) and in target absent conditions (p=0.0096). The three-way interaction between **similarity condition, target presence and age group** was also significant, $F(1.726, 177.431) = 4.296$, $p = 0.021$, ηp2 = 0.078, BF_{10} = 3.530e+184. Post hoc comparisons with FDR correction indicated that YA and OAs were significantly different from each other in each similarity condition, both when the target was present and absent (all ps<.03), with the only exception being the baseline target present condition (p=0.075).

Within-subject analyses were conducted to better examine the similarity condition results individually for each age group. A paired samples t-tests with FDR correction found for OAs performances each of the similarity conditions, both when the target was present and absent, to lead to significantly different performances (p<0.001). However, paired samples t-tests with FDR correction for YAs, found RTs between the conceptual and baseline conditions when the target was present to not be significantly different (p = 0.2995). The other conditions were significantly different from each other for YAs as well.

Accuracy

A repeated measures ANOVA on error rates demonstrated a significant effect of **similarity condition**, $F(2, 204) = 12.293$, $p < .001$, ηp2 = 0.194, BF_{10} = 4.818. Post hoc analyses with FDR correction found significantly higher error rates for both age groups in the perceptual similarity condition, in comparison to the other two conditions ($p<.001$), while the amount of errors in the conceptual and baseline conditions were not significantly different from each other ($p=0.241$).

There were no significant interactions between age group and similarity condition in error rates, $F(2, 204) = 2.369$, $p = .099$, $\eta p2 = 0.044$, $BF_{10} = 1.242$, nor significant interactions between age group and target presence, $F(1, 204) = 0.002$, $p = .961$, $\eta p2 <.001$, $BF_{10} = 1.765e+87$, or age group and set size, $F(2, 204) = .677$, $p = .511$, $\eta p2 = 0.013$, $BF_{10} = 0.054$, or similarity condition, set size and age group, or set size, target presence and age group, $F(4, 204) = 1.596$, $p = 0.177$, $\eta p2 = 0.030$, $BF_{10} = 0.257$ and $F(2, 204) = 0.82$, $p = 0.921$, $\eta p2 = 0.002$, $BF_{10} = 1.852e+87$, respectively.

There initially was a significant interaction between **age group, set size, target presence and similarity condition**, $F(3.387, 172.718) = 2.772$, $p = .037$, $\eta p2 = 0.052$, $BF_{10} = 3.146e+89$, however post hoc analyses found none of the comparisons to be significantly different between the age groups. There was no overall age effect in error rates, $F(1, 51) = 0.644$, $p = .426$, $\eta p2 = 0.012$, $BF_{10} = 0.256$.

4.3.6 Experiment 4 Discussion

In Experiment 4, I did not find a speed-accuracy trade off (Liesefeld & Janczyk, 2019) as was found in Experiment 3. However, significant differences between YA's and OA's performances, predominantly in terms of RTs, were evident. This suggests that a higher amount (on average) of distractors leads to worse performances in aging, regardless of the type of similarity amongst the objects. As for the key manipulation, I found that both age groups were impacted by the perceptual similarity condition, exemplified through longer RTs for both groups. This finding suggests a similar color between a target template (either present or absent) and distractor objects to be the biggest determinant of performances, irrespective of age. It is important to note there was a lack of a significant interaction between target presence and age group in this experiment (as both conditions were significantly different between groups). This was relative to the first experiment in which only target absent conditions were significantly different between the age groups. The difference between the two experiments, with regards to this interaction is discussed further in the General Discussion below. Additionally, there was a lack of a significant age group difference in RTs in the baseline condition when the target was present. This may be the result of OAs being capable of maintaining comparable RTs in their search performances in this condition, possibly due to the ease of identifying the presence of a target when there was a lack in either type of similarity in the display, as is the case in the baseline.

4.4 General Discussion

The main objective of the current study was to investigate the interaction between target-distractor similarity and distractor numerosity on age-related impairments in visual search. Considering the results from both experiments, it appears that the numerosity (when relatively high) is the leading determinant of age-related impairments. In other terms, a high amount of objects, not the characteristics of those objects, appear to precipitate age differences in searching a scene.

This conclusion is based on the findings from Experiment 3, which used a smaller set size (5, 7 and 10 objects); here, age differences were only present when considering OA's worsening performances compared to YAs when searching a display that did not contain the target. In contrast, in Experiment 4 I used an overall higher number of objects (i.e. 10, 12 and 15 objects). Here, age differences were found for each of the similarity conditions (with the exception of the baseline condition when the target was present). These findings would suggest that a cluttered scene is the main determinant of age impairments in VS, as the only difference between the two experiments being a higher amount of objects presented (Experiment 4). This result in Experiment 4 was reflected by a high Bayes Factor in favor of the alternative model as well. However, this conclusion should be taken with caution as I did not find an interaction between age and set size in Experiment 4, although the Bayes Factor analysis for this the interaction between age and set size in Experiment 4 demonstrated support for the alternative model.

The current study is informative due to the use of real-world objects in investigating age performances in visual search. The stimuli predominantly used in past experiments have been geometrical stimuli, therefore while those studies have been informative in suggesting that OAs have impairments when there is increased similarity between stimuli (Scialfa & Thomas, 1994), an effect that is also exacerbated when there is a higher amount of stimuli (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998), these studies are limited in suggesting how such effects translate to real-world situations. Alternatively, studies that have implemented real-world objects, have had an alternative objective than the current study, for example with the aim to investigate both levels of similarity within each trial and not manipulating the set size (Williams et al., 2009).

Concerning the similarity manipulation in the current study, this consideration was interesting due to previous research that has suggested OAs to demonstrate an impairment in discriminating against perceptual or semantic (conceptual) features (see Gellersen et al., 2023; Koutstaal et al., 2003), and are more likely to falsely recognize new objects as a previously presented object when the features are similar in either of these features (Pidgeon & Morcom, 2014). Following those previous results (Gellersen et al., 2023; Koutstaal et al., 2003; Pidgeon & Morcom, 2014), it would have been interesting to observe whether more errors or longer search performances in the current study were due to either feature of similarity (conceptual or perceptual), possibly the result of OAs needing more time to assess the similar objects, in order to discriminate between the overlapping features. However, OAs were not impaired in their search behavior in either type of similarity. In this study I found that both groups were more influenced by the perceptual similarity condition, with respect to the other two conditions. Importantly however, this perceptual similarity effect was not exacerbated in OAs.

Additionally, it has been theorized that top-down attentional guidance such as the expectation of a particular feature being presented, and the learning of features across trials, may be intact in aging (Madden, Spaniol, Bucur, & Whiting, 2007). Although this was not directly manipulated in the current experiments, it is possible that across trials, OAs were able to develop a strategy that indicated to them the features that would be relevant to study when first presented with their target object at the start of the block, later aiding them when searching for that object on the subsequent trials. This could have started with color, as this is the most obvious feature, and then could follow with the functioning of the object, and possibly the shape of the object. The lack of a manipulation controlling for the shape of the objects is a limitation of the current study. Possibly in the present experiments, the shape of objects was able to guide attention to the target object (or deter attention if distractors were a dissimilar shape compared to the target), leading to minimal effects that would have been otherwise found if the shape was not a factor.

Crucially, as it appears when comparing the two experiments, the influence of a cluttered display is more influential in precipitating OA's exacerbated effects in search. In Experiment 4 with 10, 12 and 15 objects, I found that each condition, both when the target was present and absent from the display (aside from the baseline condition when the target was present), led to age differences. The lack of an age effect in the baseline condition when the target was present is possibly the result that target present conditions in general were easier even for OAs. This (lack of an age) effect could be two-fold.

First, the target present condition in itself is also already easier, as the subject does not have to exhaustively search each item to confirm that the target is absent. Instead, the target may be quickly found in target present conditions.

Second, alternative to the perceptual and conceptual similarity conditions, the lack of a similarity amongst the objects in the baseline condition possibly made this condition additionally easier for OAs. This appears to have eliminated age effects particularly when both when the target was present and when there was no fixed similarity between the objects presented in the display.

Another potential precipitator of minimal age-effects could be the use of pictorial cues (in line with other studies on aging, see Wiegand and Wolfe, 2020) as opposed to word cues for the targets. Indeed, previous research on young adults (Malcolm & Henderson, 2009; 2010) have indicated a facilitatory effect for pictorial versus word cues. It is possible that OAs may have utilized compensatory mechanisms, following from the use of pictorial cues, in turn resulting in better performances. This hypothesis for intact OAs' performances was also suggested by Wiegand and Wolfe (2020) in which they found intact performances in their hybrid visual and memory search experiment. The researchers suggested that a possible precipitator of intact performances in aging may have been due to OAs utilizing a semantic association strategy of the real-world objects presented. Hence, future research should consider utilizing word cues, or doing a comparison of the effects of the two types of cues on visual search patterns of older adults (which, to my knowledge, has not been done yet).

Furthermore, it is also important to note the lack of a significant target presence and age group interaction in Experiment 4 compared to Experiment 3. It is possible that in the higher set size conditions of Experiment 4, this effect was null as each condition was more difficult in aging.

Overall across the two experiments presented here, the factor of similarity does not appear to lead to exacerbated age-effects in visual search performances. Instead, it appears that the main determinant of age-related difficulties in visual search are due to a high amount of objects in the search display, irrespective of any similar relationship between the objects.

Chapter 5

Age-related Oculomotor Effects in Real-World Object Search

5.1 Introduction

It is well-known from the cognitive aging research field that older adults (OAs) are worse than young adults (YAs) at identifying changes in a display (Jost et al., 2011; Ko et al., 2014), and also take longer to respond to either the presence or absence of a target (Scialfa et al., 1998). It has been suggested that gaze trajectories possibly precipitate these change detection and visual search behaviors in aging (see D'Innocenzo, Della Sala, & Coco, 2022; Wynn, Amer, & Schacter, 2020). The investigation of eye movement behaviors in OAs has been implemented in both the visual working memory (vWM) field in conjunction with implementing change detection tasks (CDT; D'Innocenzo et al., 2022, Veiel, Storandt, & Abrams, 2006) and in the attention field using visual search (Dennis et al., 2004; see Dietz, Schork, & Andre, 2016). Further reinforcing the importance of considering eye movements when assessing cognitive changes in aging, not only has it been suggested that there is a link between the cognitive domains (attention and vWM) and eye movement trajectories in aging, it has also been suggested that age-related declines in memory are precipitated by and the result of eye movement trajectories. As put by Wynn et al., "*In short, older adults remember differently because they see differently*." (Wynn et al., 2020, p. 858). Evidently, when considering OA's performances in vWM and attention paradigms, there is also significant relevance to consider oculomotor behaviors.

Measurements that have been found to be different in aging in the detection of changes in a scene are more frequent eye movements for OAs, more returns to areas already viewed, shorter saccades as well as longer fixations before providing a response (D'Innocenzo et al., 2022; Veiel et al., 2006). Furthermore, previous aging and eye-tracking studies have found OAs to be more distracted by certain types of features of distracting objects, when compared to YAs. For example, Dennis et al. (2004) presented 7, 13 and 19 stimuli with features that varied either in contrast polarity (black or white), an interior line (oriented horizontally or vertically) and shape (a square or circle). OAs and YAs were asked to respond to either the presence or absence of a target presented amongst distractors comprised of the above features. The researchers found that OAs were more distracted than YAs specifically when distractor items had the same contrast polarity as the target (Dennis et al., 2004). Additionally, YAs were more likely than OAs to fixate on distractors sharing both contrast polarity and shape as the target, while OAs did not fixate for as long on those with the same shape (Dennis et al., 2004). In sum, the manner in which features comprising items are fixated on and assessed, changes between age groups.

It is important to note that it is not always the case that there are age differences in attentional and oculomotor capture in aging. For example, Kramer, Hahn, Irwin, and Theeuwes (1999) recorded eye movements in which they examined OA's possible attentional capture of an irrelevant stimuli. In the experiment, participants were asked to identify a letter presented in a colored circle in a display (presented amongst other circles). In half of the trials, an irrelevant circle in the same color as the target was simultaneously presented (Kramer et al., 1999). Interestingly, the researchers found that performances in suppressing attention and eye movements from this distractor were similar across age groups.

Williams et al. (2009) conducted a study with real-world objects. In their study, the researchers presented OAs and YAs with a visual search display containing 12 objects in which the participants needed to count the amount of target examples were presented (0-3 possible targets out of 12). Presented amongst these items were both categorically and perceptually similar objects (0-3 each) distractors of each of these types presented in each trial. Categorically similar distractors were items that were the same type as the target, presented in a different color. Perceptually similar distractors were a different item type, presented in the same color as the target. Overall Williams et al. (2009) found that OAs fixated longer on objects overall, compared to YAs, specifically the targets. Next, the category distractors were viewed the second most frequently, disproportionately more in OAs (Williams et al., 2009). Interestingly, OAs viewed less color distractors than YAs, in opposition to the findings of Dennis et al. (2004), although it is important to note in Dennis et al. (2004), color ("contrast polarity") of items were either white or black (Williams et al., 2009).

Overall, examining eye-tracking measures allows for the investigation of understanding how OAs assess objects, while moving beyond only reaction time and accuracy measurements. However, as presented above, there are discrepancies across studies in aging that have implemented eye-tracking measures, with researchers finding color distractors to be examined more frequently by YAs (Williams et al., 2009), versus more frequently by OAs (Dennis et al., 2004). Alternatively, it has also been indicated that OAs maintain similar eye-tracking trajectories in suppressing attentional capture compared to YAs (Kramer et al., 1999). Evidently, further research is warranted in order to investigate the influence (if any) of color distractors in guiding OA's attention, as well as in general other features that guide attention in aging, such as category as suggested by Williams et al. (2009).

Current Study

The vast majority of research conducted in aging and assessing attentional capture of distractors, have used geometrical stimuli (Kramer et al., 1999; Dennis et al., 2004). Alternatively, those that have started to implement more natural contexts, have either used multiple real-world objects (Williams et al., 2009), or scenes (D'Innocenzo et al., 2022). As presented before, it is still not entirely clear the full age-related influence of attentional capture from a distractor similar in color to a target (Dennis et al., 2004; Williams et al., 2009). Accordingly, the main aim of the current study was to examine whether OAs are more captured by one distracting real-world object compared to YAs, presented in a similar color or in a similar categorical group as the target. Correspondingly, the objective of this study was to implement oculomotor parameters, in order to study whether there are possibly subtle differences in the manner in which real-world objects capture OA's attention, based on these two features: color or category.

To this aim, in the current experiment, presented along with a target object, another real-world object will be presented that will be matched to the target in two features: the color (perceptual) or the category (conceptual), similarly to Williams et al. (2009). My aim with these manipulations was to examine whether age-related eye movement trajectories are guided towards another object based on color or based on category. Interestingly, Williams et al. (2009) found category distractors were viewed the second most frequently (after targets), and disproportionately more in OAs. However, in Williams et al. (2009), category distractors would be a different exemplar of the same type of object, for example, if the target was a yellow drill, a category distractor would be a different drill, in a different color. Instead, as it was found that OAs were more likely to look longer at these type of distractors, I implemented two levels category distractors (referred to as conceptual) in the current study: one that was the exact same image in a different color, and another that was the same type of object, however a different type (for example two different types of axe), also in a different color as Williams et al. (2009). The motivation of this followed from the lack of significant age-related performance declines in the previous experiments concerning both types of similarity (perceptual and conceptual), as presented above (predominately using geometrical stimuli) and finding differential conclusions as to whether color distractors capture OAs attention more (Dennis et al., 2004), or category (Williams et al., 2009).

I also implemented the same level of manipulations for the perceptual condition: a target that was matched to the target in the exact color, or in a slightly different color (black compared to gray for example). Herein forth, I will refer to these in-between color changes as: mid-level colors. This investigation is interesting as it has been suggested that sensory and perceptual declines are the precipitators of age-related declines in cognitive tasks (see Scialfa, 2002), therefore it is of interest to consider at which level these perceptual declines may extend in aging. For example, it is of interest to investigate whether age-related perceptual declines occur when the color between two objects (target and distractor) are the exact same color, or also when the colors are slightly similar (black and gray for example).

For this investigation, I considered the following eye-movement measurements: the direction of the first saccade (target, target side of the screen, distractor or distractor side of the screen), the reaction time (RT) to when participants accurately went first to the target, as well as the velocity, duration, amplitude and latency of first saccades to the target or distractor. These measurements were chosen based on previous studies both in healthy aging (Kramer et al., 1999; Scialfa & Joffe, 1997; Scialfa & Joffe, 1998; Veiel et al., 2006) and a recent study using objects of differing colors looking at healthy controls and participants with Parkinson's disease (Fooken et al., 2022). Other measurements, discussed above, such as more returns to areas already viewed, and longer fixations before providing responses for example, in the assessment of scenes (D'Innocenzo et al., 2022), were not measured here due to experimental set-up of the current experiment. In the current experiment, there were only two objects presented, and the moment that the participants eyes' fixated on the target object, the screen went blank and registered their fixation. As such, it could not be assessed (nor was it the main research question), how many times participants returned to an area or the amount of fixation time before responding. Instead, the main research question in the current experiment was whether there are age differences in the trajectory of eye movements when participants are presented with one predefined target real-world object and one distractor object, that are either similar in perceptual (two levels) or conceptual (two levels) features.

Key predictions for this study are that OAs will be slower overall in arriving to the target object as well as make more errors by looking first at the distractor object. It can be hypothesized that OAs will commit more errors due to decreased inhibition, possibly as the result of reduced cognitive control (see Borges, Fernandes, & Coco, 2020, but also see Kramer et al., 1999). Moreover, whether this would be more in the perceptual or conceptual factor (and whether both levels will have the same amount of influence), is the main question addressed in the current study. This investigation of the different levels of conceptual distractors will look closer at which type of conceptual feature possibly guide OA's eye movements. Furthermore, the investigation of the two levels of perceptual will additionally be informative as it will further investigate whether perceptual features guide age-related eye trajectories.

5.2 Experiment 5 Methods

5.2.1 Participants

Participants were recruited from previous experiments conducted by our group, via public flyers, and community advertisements. I aimed for 30 participants in both age groups based on a power analyses performed in G Power 3.1.9.7 (Faul, Erdfelder, Buchner, & Lang, 2009) with an 80% power and an effect size of 0.25, suggesting a total sample size of 22. For young adults (YAs), I set the inclusionary criteria that participants must be between 20 and 30 years old and have normal or corrected-to-normal vision in order to be eligible to take part in the study. For older adults (OAs), the inclusionary criteria were that participants must be between 65 and 75 years old and have normal or corrected-to-normal vision. To ensure the cognitive health of the OA sample, OA participants were administered the MoCA cognitive test before the start of the experiment or if they were a participant in one of our group's previous studies, they already had a MoCA pc score above 19.01 within the last 6 months (Conti, Bonazzi, Laiacona, Masina, & Coralli, 2015; Nasreddine et al., 2005). Details of the two samples are reported in **Table *5***. Participants provided written, informed consent to participate in the study, and received monetary reimbursement of 6 Euro (or if the participant refused the monetary compensation, they received a "gadget" from the center). The study was approved by the Università degli Studi di Trento Research Ethics Committee (Protocol No: 2020-021).

5.2.2 Stimuli and Apparatus

The experiment was administered on a 23.6-inch color monitor at a display resolution of 1920 (H) x 1080 (V) pixels. Each participant's left eye was recorded (unless the system was unable to calibrate the left eye, and therefore the right-eye was recorded) with a sampling rate of 2000 Hz (except for one YA subject at 1000 Hz due to a technical error). Eye-tracking was recorded through an SR Research EyeLink 1000 desktop eye-tracker. A chin rest was used that fixated participants at an 84 cm distance from the screen.

All stimuli were downloaded from the online repository of Aude Oliva Lab at MIT (http://olivalab.mit.edu/MM/index.html). The object images used in this study were collected from the "Object Categories" repository (cited in Konkle, Brady, Alvarez, and Oliva, 2010). There were 96 original image objects that I used that were then edited in Adobe Photoshop into four main color groups: black (RGB: 0, 0, 0); blue (RGB: 13, 69, 100); brown (RGB: 104, 53, 2); green (RGB: 4, 77, 48). Tonal values were adjusted afterwards when needed.

Additionally, each image in the four-color groups was edited with a tonal value of "2" in order to have an additional four mid-level colors: mid-level black; mid-level blue; mid-level brown; mid-level green. With these mid-level color edits, this left eight total color groups of images for this experiment, therefore there were 768 total images. As some of the original image objects were still either very light or very dark, after these initial edits were done, some of the images then needed to also have the luminosity changed. Please see the Appendix D for image details. Moreover, each of the 768 objects were also divided into four main object categories: 1) Tools / Appliances, 2) Furniture, 3) Cook / Tableware and 4) Clothing.

Objects were presented at a distance of 5.67 visual degrees from the fixation point. The target image was presented within a 30-degree radius and the distractor image was presented on the opposite side of the screen relative to the target image, also within a 30-degree radius. During the experiment, on each trial there were two images presented, one on the right-hand side of the screen and one on the left-hand side of the screen. Each image was presented with a 0.30-degree jitter. The background color of the display was set to a light cream color (RGB: 250, 240, 190) in order to not be too tiresome for the eyes throughout the duration of the experiment. There was a black fixation circle (RGB: 0, 0, 0) in the center of the screen that the participants were asked to fixate on in between each trial and at the start of each trial. If the eye-tracker did not register that the participant was fixating on the circle, it would not proceed to the next trial and would not show the images for the next trial. The circle would also turn red (RGB: 255, 0, 0) when this would occur, indicating to the participant to try to fixate more precisely on the circle.

5.2.3 Design and Procedure

At the start of the experiment, participants gave their informed consent. Next if they were a YA they provided demographic information, including age, gender and education. If the participant was an OA, if a valid MOCA test less than six months old from our group was not already available, they were administered the MOCA (Nasreddine et al., 2005).

Demographic general information including age, gender and education is listed in **Table *5***. Participants eligible to take part in the study then proceeded to the main experiment. The first step of the main experiment was to ask the participant to sit comfortably in the chair and to place their chin on the chinrest and accordingly adjust the height for a comfortable position. Once the participant indicated that they were comfortable, participants were told the instructions and shown the instructions within the experiment. The experiment program was created using MATLAB code and was implemented through the SR Research EyeLink Experiment Builder (SR Research, 2004).

Table 5

General demographics for participants in the Experiment 5 with Eye-Tracking

	Young adults	Older adults
	n = 25	n = 25
Age	m = 24.84 yrs. SD = 3.35	m = 68.92 yrs. SD = 2.36
Gender		
Female	18	17
Male	7	8
Years of education	m = 16.76 yrs. SD = 2.68	m = 15 yrs. SD = 4.36
MOCA score	n.a.	24.52 SD = 2.70

Note. Demographic information includes final sample analyzed after excluding outliers.

yrs.= years

n.a.= not applicable

m = mean

SD = standard deviation

At the beginning of the experiment, participants were told that at the start of every block, they would be presented with a new image that they would need to search for on each following trial for that block. The target image at the start of the block would be presented in the center of the screen at a 4.56° visual angle.

In the proceeding trials, this image would be presented along with another distractor image that the participant was told needed to be ignored. The target and distractor images were presented at a 1.52° visual angle. The participants were told that the target image could be presented either on the left or the right-hand side of the screen and the other image would be presented on the opposite side of the screen. Participants were instructed to direct their gaze towards the target image. If the participant first looked directly at the target image (ignoring the distractor image), the fixation circle would turn green (RGB: 0, 255, 0), whereas if the participant first looked at the other image (distractor) and then the target, the fixation circle would turn red.

After the participant had fixated on the images, and the images were no longer presented on the screen, the fixation circle (after turning either green or red) returned to black. When the participant was ready to see the next trial of images, they had to press the spacebar on the keyboard in front of them, and then the next image pair would be presented. If the eye-tracker did not register their fixation, the central fixation would turn red until the participant's pupil was successfully registered. Once the pupil was registered and the participant had pressed the spacebar, the next trial of images would be presented. Participants were also told that they could take a break throughout the experiment in order to rest their eyes. An option for a break was given every 35 trials from the start of the block and was verbally given at the start of each new block.

Participants were given visual examples during the instructions explanation however were not told of the similarity between object pairings that would occur in the experiment trials.

5.2.3.1 Eye-tracker Calibration

The nine-point calibration and validation were registered on one eye, typically the left-eye, unless it was not successful and the right-eye needed to be calibrated. All participants were recorded at a 2 kHz sampling rate, with the exception of one young participant recorded at 1 kHz, due to a technical issue in the experiment set-up for that participant. Calibration of the participants' eyes required following a black dot on a white screen (RGB: 255, 255, 255). The dot moved to different angles on the screen until the eye-tracker recorded the pupil appropriately at each location. Of the recruited participants, calibration was unsuccessful for two YA participants and three OA participants. The calibration for one additional OA participant was difficult to maintain and therefore the participant only completed four out of the eight blocks due to fatigue and time constraints.

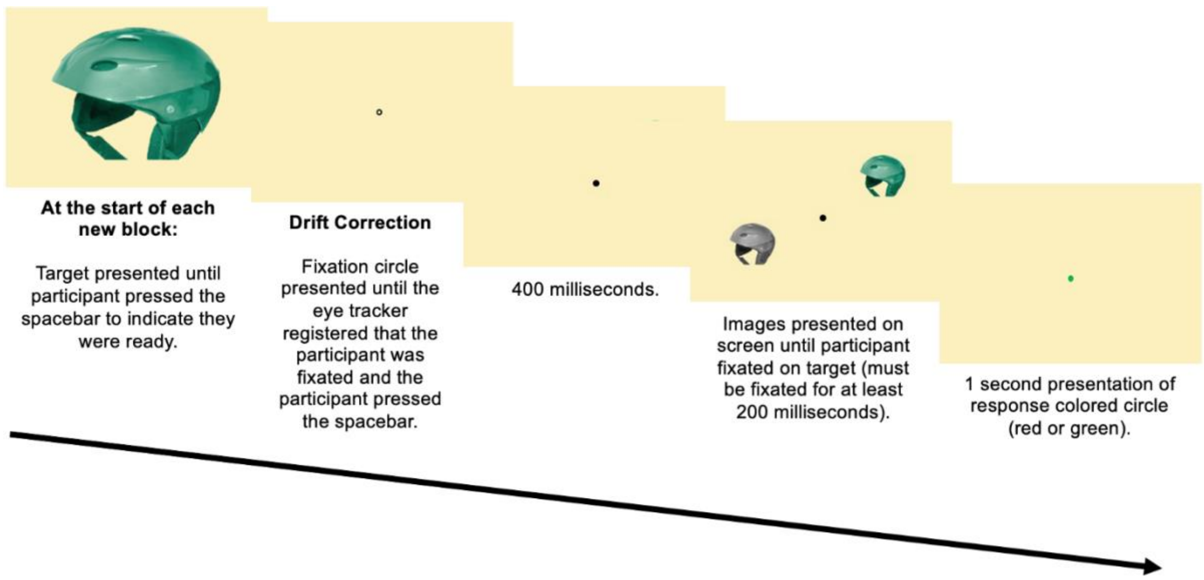
Once calibration and validation of the participant's eye were successful and the participants said that they were ready, each participant started the practice trials which on average were about 20 trials, depending on how long it took the participant to understand the experiment.

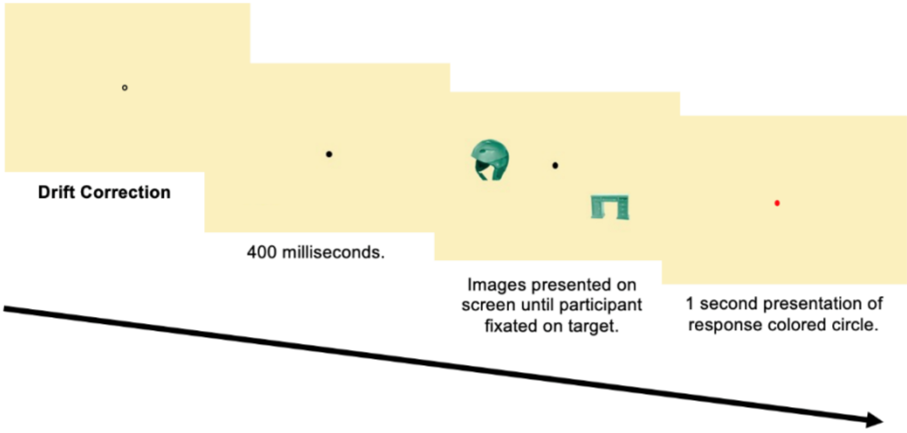
5.2.3.2 Eye-tracking Experiment

During the experiment, each participant was presented with a total of eight blocks and therefore eight target objects. Each participant received a randomized set of trials, so that not all participants had the same eight target objects. OAs and YAs were counterbalanced to see the same trial files, for example OA Subject 1 had the same eight target objects as YA Subject 1. Additionally, all eight targets across the duration of the full experiment for each participant was counterbalanced, ensuring that everyone would have each of the eight colors (including the mid-level colors) presented as a target once and each of the four categories presented as a target two times. An example of a trial is presented in Figure *19*.

Figure 19

Example of Eye-tracking Experiment Trials





Note. Images not to scale.

Figure 19 shows an experiment example of the start of a block and then two trial examples. First at the start of the block (top row), a green helmet is presented as the target. Next, a drift correction occurs in order to ensure that the eye tracker registers that the participant is fixated and then the participant (or the experimenter) can press the spacebar to initiate the next trial. Following this, a black circle is presented for 400 milliseconds and then two images are presented. In this example, the two images presented are: 1) the target (green helmet) and 2) the distractor (gray helmet). If the participant goes first to the target (as in the first example above), the next screen will present the fixation circle in green. Next (bottom row of **Figure 19**), after the following drift correction for the proceeding trial is presented, a black circle is presented for 400 milliseconds. Following this, the next images are then presented: the bottom row demonstrates an example in which the participant went to the distractor first (green desk), therefore the fixation circle turns red on the next screen for this trial.

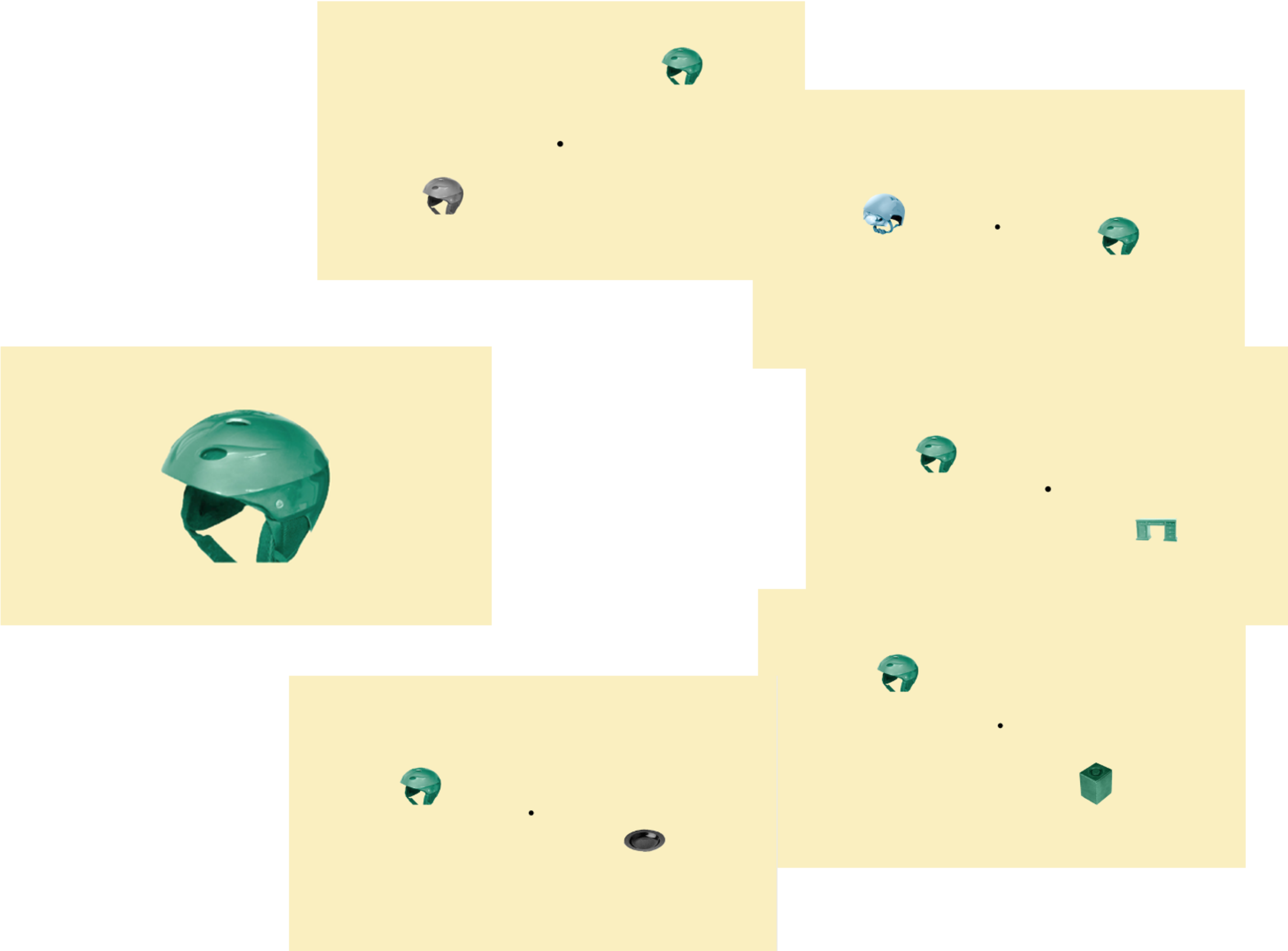
There were eight blocks in total for the experiment, and 60 trials in a block. In total, across the whole experiment, there were 480 trials. Within each block, participants were given the option after 35 trials to take a break if needed. Within each block, each manipulation of the distractor image along with the target image were presented in a randomized order.

There were five different main conditions in which the manipulations were the relation between the target and distractor object presented. Across the full duration of the experiment, there were 96 total trials of each condition, with 12 trials for each condition within each block: Conceptual – Same; Conceptual – Similar; Perceptual – Same; Perceptual – Similar; Baseline.

In the **Conceptual – Same condition** Figure *20* top panel, the distractor was the exact same image, presented in a different color (mid-level black in Figure *20*). For example, if the target was the mid-level green color and a helmet (Figure *20*), the distractor would be the exact same type of helmet, however in one of the other six color options (not green or mid-level green). In the **Conceptual – Similar condition** Figure *20* second panel the distractor image was the same exemplar type, but not the same image. For example, if the target was a helmet the distractor would be a different helmet. Akin to Condition 1, the distracting helmet, could not be green or mid-level green. In the **Perceptual – Same condition** Figure *20* third panel the distractor was the same color, and in alignment with the parameters set for the conceptual conditions, the distractor could not be from the same category (four categories mentioned above: 5.2.2). In the **Perceptual – Similar condition** Figure *20* fourth panel the distractor was from the corresponding mid-level color group, but it could not be the same category. For example, in which the target helmet image was mid-level green, the distractor image in this condition would be from the main color group green. Finally, in the **Baseline Condition**, the distractor was an image from a different color group and a different category, including green or mid-level green Figure *20* fifth panel. Image positions were balanced as well as whether the target image was presented on the right-hand or left-hand side of the screen.

Figure 20

Eye-tracking Experiment Condition Examples



Note. Images not to scale.

After completing the experiment, participants were offered the chance to complete an exploratory survey asking about their knowledge of the manipulations between target and distractors and their usage of a technique, and also possible strategy usage. As this survey was explorative, and only a small portion of subjects completed it due to time constraints, the responses will not be described here, however are available upon request.

In general, for the full procedure of the study (consent and experiment) for YAs took on average 60 minutes and OAs (consent, cognitive test and experiment) took 1 hour and 30 minutes.

5.2.4 Data analysis

There were 25 YAs for the final analyses (mean age = 24.84 years, SD = 3.35, 18 female). One OA was excluded from the final analyses for not maintaining adequate fixation throughout the experiment, leaving 25 OAs for the final analyses (mean age = 68.92 years, SD = 2.36, 17 female). Saccade data was downloaded from the Data Viewer software (SR Research) and subsequently analyzed in Excel, JASP and MATLAB. Behavior data (reaction times) was automatically saved from the program into an Excel format for each subject, inclusionary details for the subjects in reaction times were calculated in MATLAB (see Appendix D).

Analyses focused on the direction of the first saccade (target, target side of the screen, distractor or distractor side of the screen), reaction times for subjects to correctly arrive at the target, and the velocity, duration, amplitude and latency of first saccades, separated between first saccades that either went to the target or the distractor, and then combined with the respective side of the screen. Repeated measures ANOVAs were conducted in JASP (http://www.jasp-stats.org) with the between-subjects factor of age group (OA, YA) and the within-subjects factors of Relational Level (conceptual-same, conceptual-similar, perceptual-same, perceptual-similar, baseline). Greenhouse-Geiser corrections were used when appropriate. In addition, Bayesian statistic ANOVAs were conducted using JASP (Van Den Bergh et al., 2020). Bayes Factor 10 (BF_{10}) is reported which is the value of the likelihood of the alternative model compared to the null model. BF_{10} is reported following the results of the corresponding ANOVA results. A Bayes Factor (BF_{10}) value higher than 1 is considered as demonstrating support for the alternative hypothesis, while a Bayes Factor value less than 1 is considered as demonstrating support for the null hypothesis. Significant interactions were further investigated either with independent samples t-tests to investigate comparisons between groups, or paired samples t-tests to disentangle results within-groups, all with false discovery rate corrections applied (FDR; Benjamini & Hochberg, 1995). Post hoc t-tests and FDR corrections (Groppe, 2023) were all performed in MATLAB.

5.2.5 Results

5.2.5.1 Ocular Reaction Times

First, reaction time (RT) measurements for correct responses were determined for the time that each participant took to leave the fixation and arrive at the target. Please see Appendix D for exclusionary criteria.

The results indicated no significant effect of Relational Level, $F(4, 192) = 1.441$, $p = 0.222$, $\eta^2_p = 0.029$, $BF_{10} = 0.103$, nor was there an interaction between age group and Relational Level, $F(4, 192) = 0.716$, $p = 0.582$, $\eta^2_p = 0.015$, $BF_{10} = 5.616$. There was however an overall age effect of RTs, $F(1, 48) = 14.665$, $p < .001$, $\eta^2_p = 0.234$, $BF_{10} = 53.202$, with longer RTs for OAs. See Figure 21 below for young and older adults' reaction times.

Figure 21

Young and Older Adults' Reaction Times in Eye-tracking Experiment

5.2.5.2 Saccade Analyses

I calculated the following eye-movement saccade measurements: 1) the direction of the first saccade (directly to the target, to target side of the screen, directly to the distractor and the distractor side of the screen). Direction analyses indicated a low amount of responses for first saccades arriving only at the target side of the screen or the distractor side of the screen (but not arriving at the respective images), therefore the preceding analyses were separated into: a) target, b) target and target side of the screen combined, c) distractor, d) distractor and distractor side of the screen combined. These following analyses included the: 2) velocity, 3) duration, 4) amplitude and 5) latency measurements of first saccades.

Direction of first saccades

To the Target Object

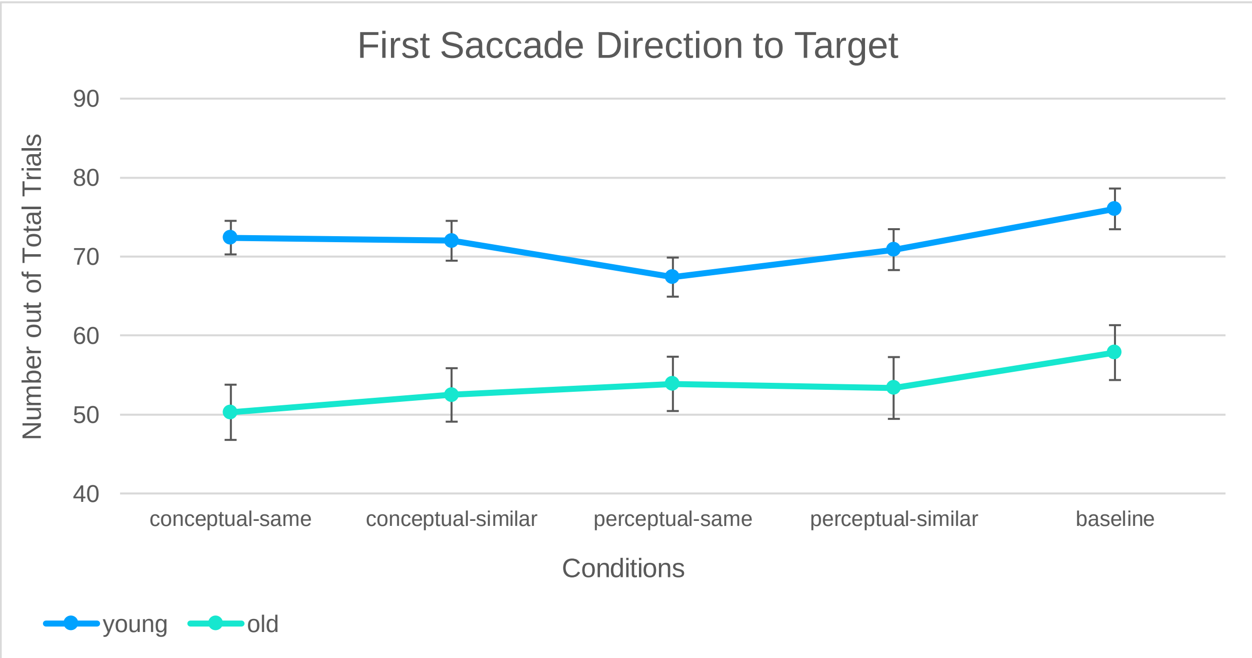
A repeated measures ANOVA found an effect of Relational Level, $F(4, 192) = 17.099$, $p < .001$, $\eta^2_p = 0.263$, $BF_{10} = 1.300e+8$, of age, $F(1, 48) = 18.879$, $p < .001$, $\eta^2_p = 0.282$, $BF_{10} = 161.586$, and of their interaction, $F(4, 192) = 6.856$, $p < .001$, $\eta^2_p = 0.125$, $BF_{10} = 2.046e+10$. Post hoc follow-up analyses found each of the five Relational Level conditions to be significantly different between the age groups ps <0.003.

In order to better understand the results, within-group analyses were then conducted on the count of first saccades arrived at the target. First, for OAs, a repeated measures ANOVA found an effect of Relational Level, $F(4, 96) = 10.352$, $p < .001$, $\eta^2_p = 0.301$, $BF_{10} = 27389.749$. Post hoc follow-up analyses found all of the four Relational Level conditions significantly different from baseline (ps <.001). OAs had a higher instance when it was a baseline condition, to arrive directly to the target.

Then for YAs, a repeated measures ANOVA found an effect of Relational Level, $F(4, 96) = 10.199$, $p < .001$, $\eta^2_p = 0.298$, $BF_{10} = 22869.350$. Post hoc follow-up analyses found all four Relational Level conditions were significantly different from baseline (ps <.01). Similar to OAs, YAs also had a higher instance when it was a baseline condition, to arrive directly to the target. See Figure *22* below for a visualization of the amount of first saccades that went to the target object, for young and older adults.

Figure 22

Young and Older Adults' First Saccade Direction to Target Object in Eye-tracking Experiment



To the Target Area

Ten YAs and one OA had to be removed from this analysis due to not having enough first saccades arriving first at the target area. The results of first saccades arriving to the target area found no significant effect of Relational Level, $F(4, 148) = 0.362$, $p = 0.835$, $\eta^2_p = 0.010$, $BF_{10} = 0.024$, nor an interaction between Relational Level and age group, $F(4, 148) = 0.432$, $p = 0.786$, $\eta^2_p = 0.012$, $BF_{10} = 0.039$. There was an overall marginally significant effect of age, $F(1, 37) = 4.067$, $p = 0.051$, $\eta^2_p = 0.099$, $BF_{10} = 1.582$, with OAs more likely to arrive with their first saccades to the target area.

To the Distractor Object

Four YAs had to be removed from this analysis due to not having enough first saccades going towards the distractor.

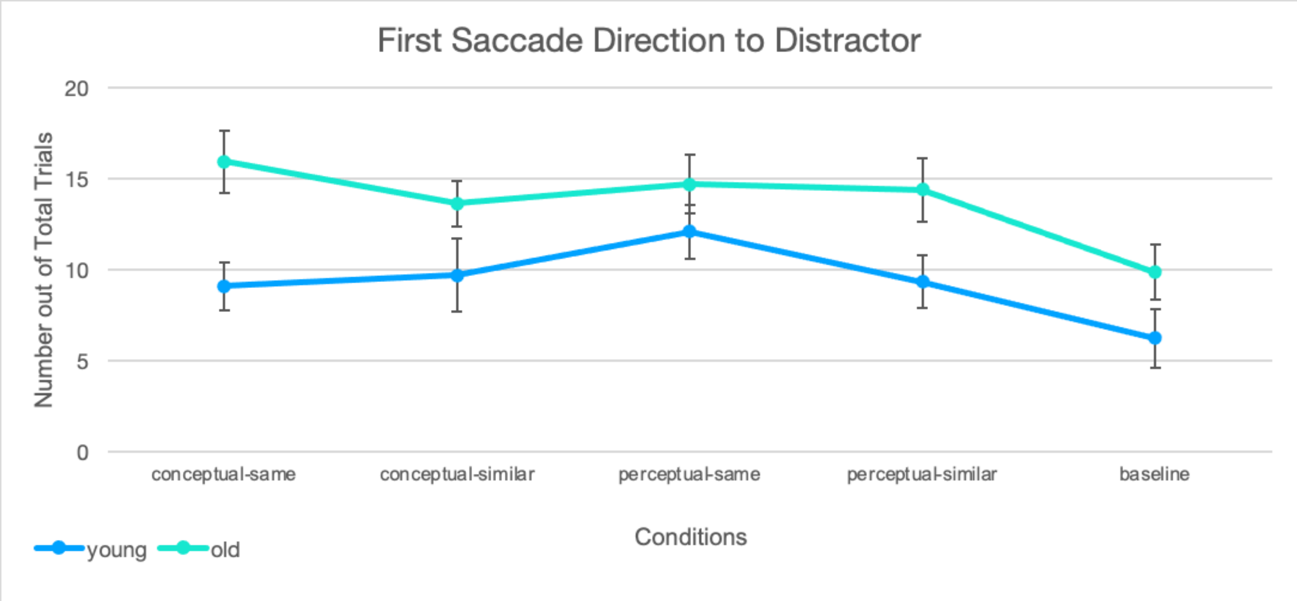
The results of the ANOVA indicated a significant effect of Relational Level, $F(3.361, 147.866) = 13.559$, $p < .001$, $\eta^2_p = 0.236$, $BF_{10} = 8.371e+6$. Post Hoc follow-up analyses found each of the four Relational Level conditions were significantly different from the baseline condition ps= <.001. Reflecting the target direction analyses described above, this analyses of the first saccade arriving to the distractor found the instances of this to be lowest, for both age groups, in the baseline condition, relative to the other four Relational Level conditions.

There was no significant age group interaction with Relational Level, $F(3.361, 147.866) = 2.125$, $p = 0.092$, $\eta^2_p = 0.046$, $BF_{10} = 1.744e+7$. There was an overall age group effect, $F(1, 44) = 4.749$, $p = 0.035$, $\eta^2_p = 0.097$, $BF_{10} = 1.972$. OAs had a higher instance overall of going to the distractor with their first saccades. See Figure *23* below of the amount of first saccades that went to the distractor object, for young and older adults.

In order to better understand the results, I then conducted within-group analyses. First for OAs, a repeated measures ANOVA found an effect of Relational Level, $F(4, 96) = 7.846.018$, $p < .001$, $\eta^2_p = 0.246$, $BF_{10} = 1202.004$. Post hoc analyses found each of the four Relational Level conditions were significantly different from the baseline condition ps= .008. Then, looking specifically at YAs, a repeated measures ANOVA found an effect of Relational Level, $F(4, 80) = 8.594$, $p < .001$, $\eta^2_p = 0.301$, $BF_{10} = 2258.013$. Post hoc analyses found each of the four Relational Level conditions were significantly different from the baseline condition ps < .001. For both groups, the baseline condition had significantly lower instances of first saccades being directed towards the distractor image.

Figure 23

Young and Older Adults' First Saccade Direction to Distractor Object in Eye-tracking Experiment



To the Distractor Area

Twelve YAs were removed from this analysis as well as 5 OAs. The results of the ANOVA indicated no significant effect of Relational Level, $F(4, 124) = 2.249$, $p = 0.068$, $\eta^2_p = 0.068$, $BF_{10} = 0.425$. There was no significant age group interaction with Relational Level, $F(4, 124) = 1.746$, $p = 0.144$, $\eta^2_p = 0.053$, $BF_{10} = 0.517$. There was no overall age group effect, $F(1, 31) = 3.224$, $p = 0.082$, $\eta^2_p = 0.094$, $BF_{10} = 1.379$.

In order to better understand the results, within-group analyses were then conducted on the count of first saccades that arrived to the distractor area. First, for OAs, a repeated measures ANOVA found no effect of Relational Level, $F(4, 76) = 1.437$, $p = 0.230$, $\eta^2_p = 0.070$, $BF_{10} = 0.25$.

Alternatively for YAs, a repeated measures ANOVA found an effect of Relational Level, F(4, 48) = 3.123, p =0.023, $\eta^2_p = 0.206$, $BF_{10} = 2.489$. Post hoc follow-up analyses however found none of the Relational Level conditions to be significantly different.

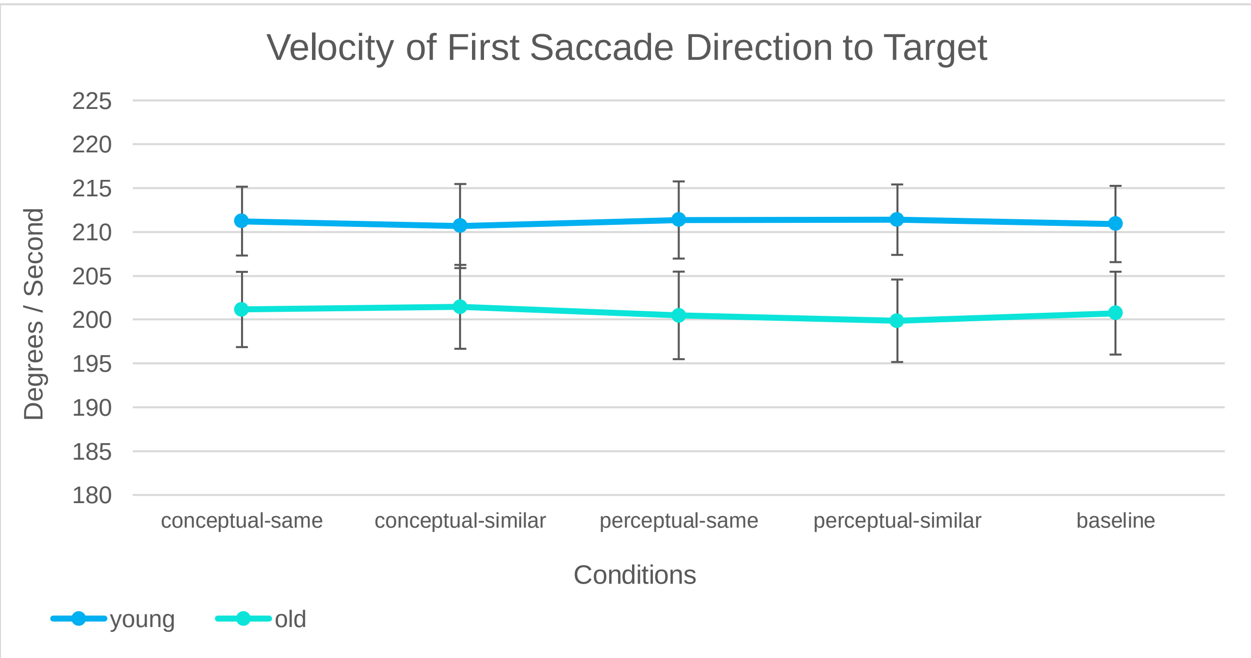
Velocity of first saccades

To the Target Object

Next, I considered the velocity of first saccades. I found, considering the first saccades that arrived at the target object, there was no effect of Relational Level, $F(3.276, 157.251) = 0.119$, $p = 0.958$, $\eta^2_p = 0.002$, $BF_{10} = 0.013$, of age, $F(1, 48) = 2.729$, $p = 0.105$, $\eta^2_p = 0.054$, $BF_{10} = 0.550$, or of their interaction, $F(3.276, 157.251) = 0.488$, $p = 0.707$, $\eta^2_p = 0.010$, $BF_{10} = 0.015$. See Figure 24 below for a visualization of the velocity of first saccades that went to the target object, for both young and older adults.

Figure 24

Young and Older Adults' Velocity of First Saccade to Target Object in Eye-tracking Experiment



To the Target Object and Target Area

Next, combining both target object and target area analyses, there was no significant effect of Relational Level, $F(4, 192) = 0.473$, $p = 0.755$, $\eta^2_p = 0.010$, $BF_{10} = 0.023$, nor interaction with age group, $F(4, 192) = 0.494$, $p = 0.740$, $\eta^2_p = 0.010$, $BF_{10} = 0.032$. There was however an overall age group effect, $F(1, 48) = 3.927$, $p = 0.053$, $\eta^2_p = 0.076$, $BF_{10} = 0.656$. The velocity of arriving directly to the combined target and target area was higher in YAs than in OAs.

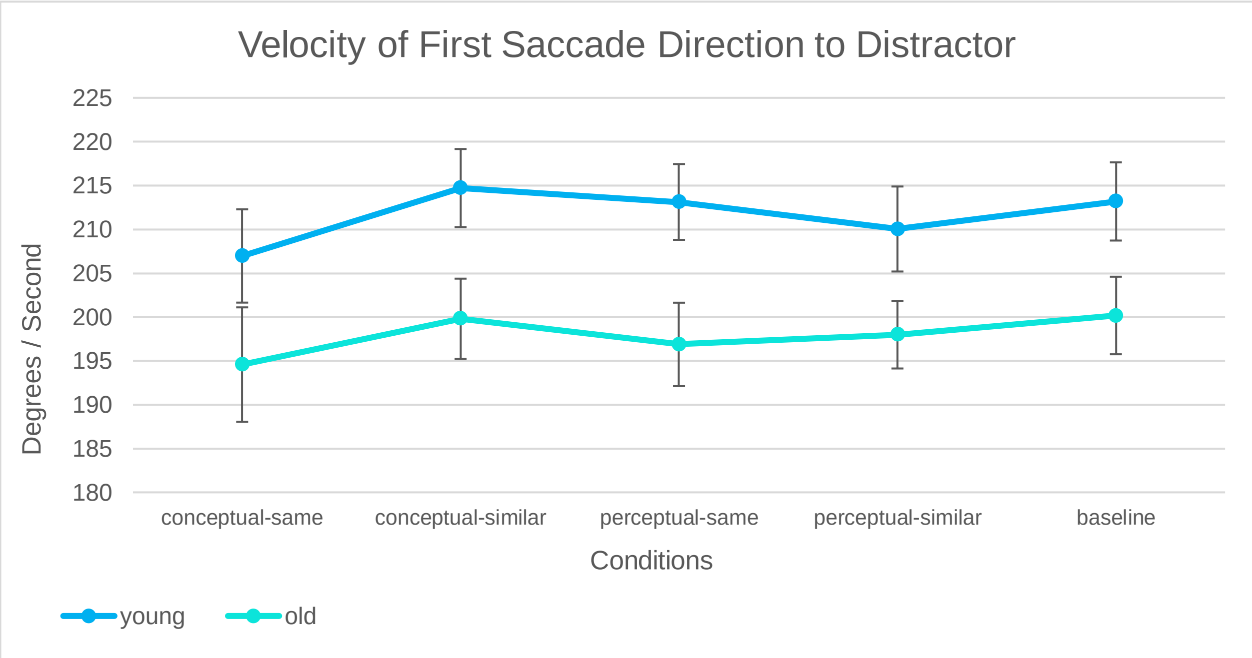
Arriving Directly to the Distractor Object

Data from four YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found a marginally significant effect of Relational Level, $F(3.158, 138.940) = 2.577$, $p = 0.053$, $\eta^2_p = 0.055$, $BF_{10} = 0.646$. Post Hoc analyses found none of the conditions to be significantly different from each other in terms of the velocity of the first saccade towards the distractor.

There was no age group interaction with Relational Level, $F(3.158, 138.940) = 0.313$, $p = 0.826$, $\eta^2_p = 0.007$, $BF_{10} = 1.767$. There was an overall age group effect, $F(1, 44) = 4.825$, $p = 0.033$, $\eta^2_p = 0.099$, $BF_{10} = 1.987$, with YAs demonstrating the highest velocity in arriving to the distractor object. See Figure *25* below for a visualization of the velocity of first saccades that went to the distractor object, for young and older adults.

Figure 25

Young and Older Adults' Velocity of First Saccade to Distractor Object in Eye-tracking Experiment



Arriving Directly to the Distractor Object and Area

Next, I analyzed the velocity of the first saccades that arrived to the combined distractor object and area. For this analysis, four of the YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found no effect of Relational Level, $F(2.931, 128.966) = 1.103$, $p = 0.350$, $\eta^2_p = 0.024$, $BF_{10} = 0.061$, nor interaction with age, $F(2.931, 128.966) = 0.754$, $p = 0.519$, $\eta^2_p = 0.017$, $BF_{10} = 0.143$. There was an overall age group effect, $F(1, 44) = 5.223$, $p = 0.027$, $\eta^2_p = 0.106$, $BF_{10} = 2.354$. YAs had the highest velocity of arriving to the distractor object and area with their first saccades.

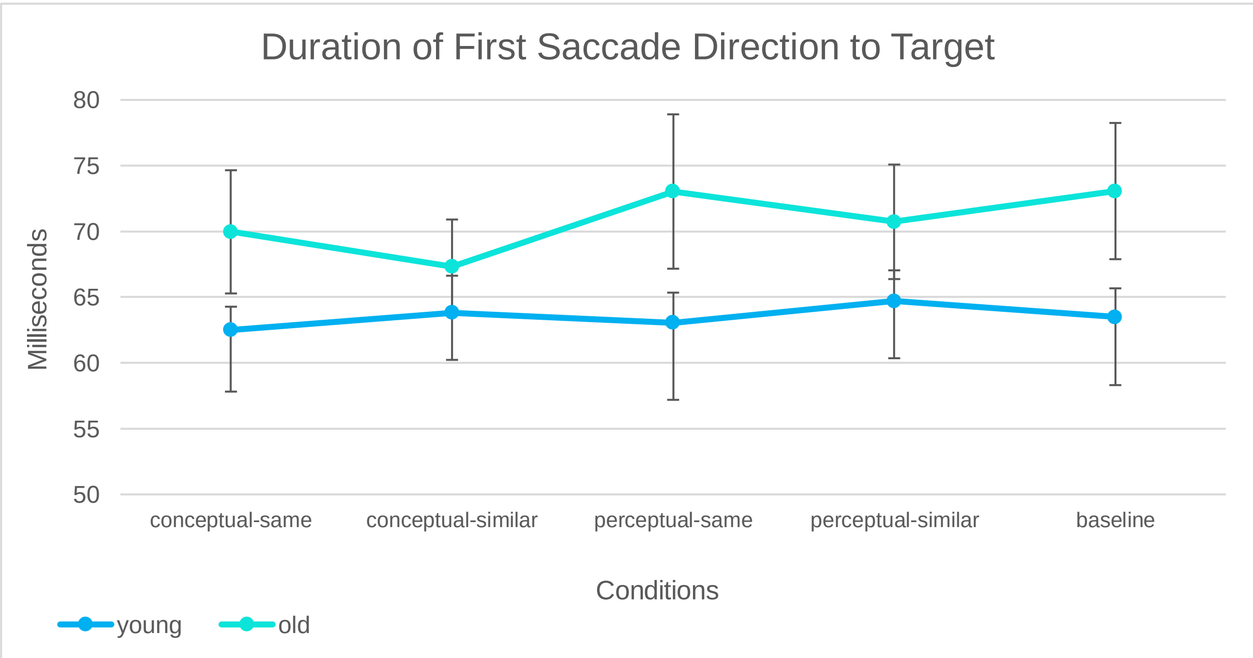
Duration of first saccades

Arriving Directly to the Target Object

Next, for the analyses of the duration of the first saccades that arrived to the target object. A repeated measures ANOVA found no effect of Relational Level, $F(2.715, 130.314) = 1.566$, $p = 0.204$, $\eta^2_p = 0.032$, $BF_{10} = 0.118$, of age, $F(1, 48) = 2.106$, $p = 0.153$, $\eta^2_p = 0.042$, $BF_{10} = 0.874$, or of their interaction, $F(2.715, 130.314) = 1.931$, $p = 0.134$, $\eta^2_p = 0.039$, $BF_{10} = 0.108$. See Figure 26 below of the duration of first saccades that went to the target object, for both young and older adults.

Figure 26

Young and Older Adults' Duration of First Saccade to Target Object in Eye-tracking Experiment



Arriving Directly to the Target Object and Area

Next, for the analyses of the duration of the first saccades that arrived to the target object and area. A repeated measures ANOVA found no effect of Relational Level, $F(2.492, 119.598) = 0.795$, $p = 0.478$, $\eta^2_p = 0.016$, $BF_{10} = 0.036$, of age, $F(1, 48) = 1.635$, $p = 0.207$, $\eta^2_p = 0.033$,

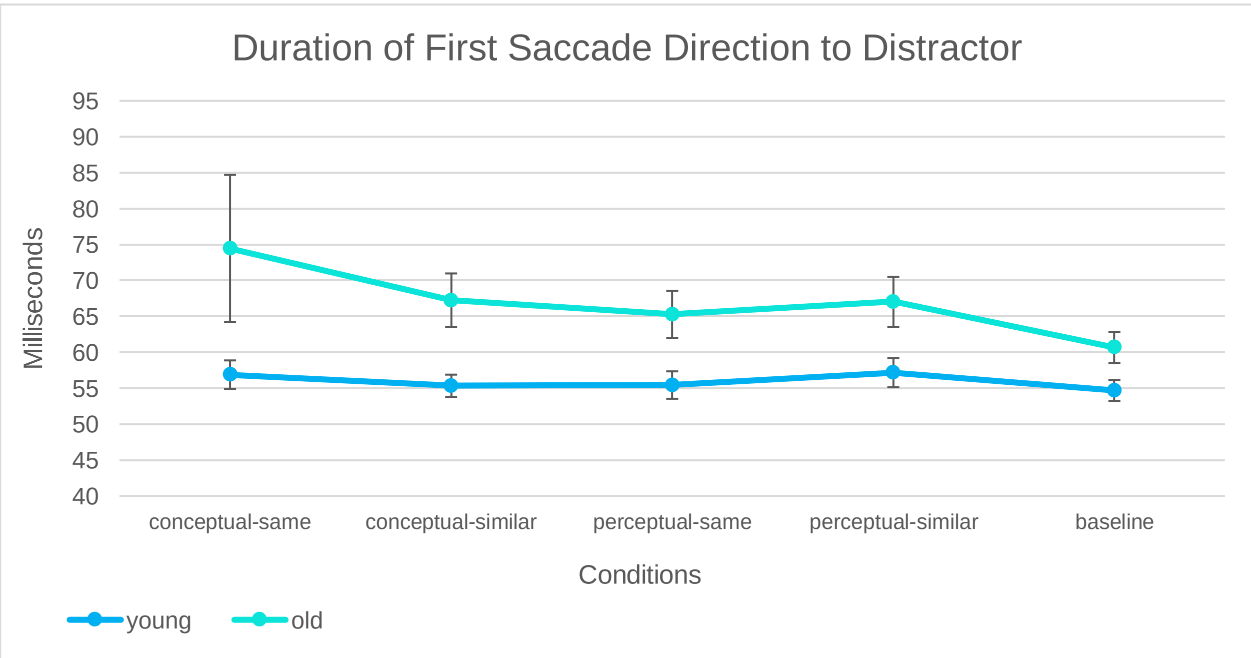
BF_{10} = 0.751, or of their interaction, $F(2.492, 119.598) = 1.931$, $p = 0.142$, $\eta^2_p = 0.038$, BF_{10} = 0.026.

Arriving Directly to the Distractor Object

Next, I analyzed the duration of the first saccades that arrived to the distractor object. For this analysis, akin to the velocity analyses of the first saccade directed towards the distractor, four of the YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found no effect of Relational Level, $F(1.44, 63.515) = 1.502$, $p = 0.231$, $\eta^2_p = 0.033$, $BF_{10} = 0.173$, or interaction with age, $F(1.44, 63.515) = 0.799$, $p = 0.417$, $\eta^2_p = 0.018$, $BF_{10} = 0.558$. There was an overall age group effect, $F(1, 44) = 6.130$, $p = 0.017$, $\eta^2_p = 0.122$, $BF_{10} = 3.272$. The duration of first saccades arriving directly to the distractor object was highest in OAs. See Figure 27 below of the duration of first saccades that went to the distractor object, for both young and older adults.

Figure 27

Young and Older Adults' Duration of First Saccade to Distractor Object in Eye-tracking Experiment



Arriving Directly to the Distractor Object and Area

Next, I analyzed the duration of the first saccades that arrived to the distractor object and area. For this analysis, akin to the velocity analyses of the first saccade directed towards the distractor, four of the YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found no effect of Relational Level, $F(1.488, 65.464) = 2.846$, $p = 0.080$, $\eta^2_p = 0.061$, $BF_{10} = 1.641$, or interaction with age, $F(1.488, 65.464) = 0.855$, $p = 0.400$, $\eta^2_p = 0.019$, $BF_{10} = 5.044$. There was an overall age group effect, $F(1, 44) = 5.948$, $p = 0.019$, $\eta^2_p = 0.119$, $BF_{10} = 3.014$. The duration of first saccades arriving directly to the distractor object and area was highest in OAs.

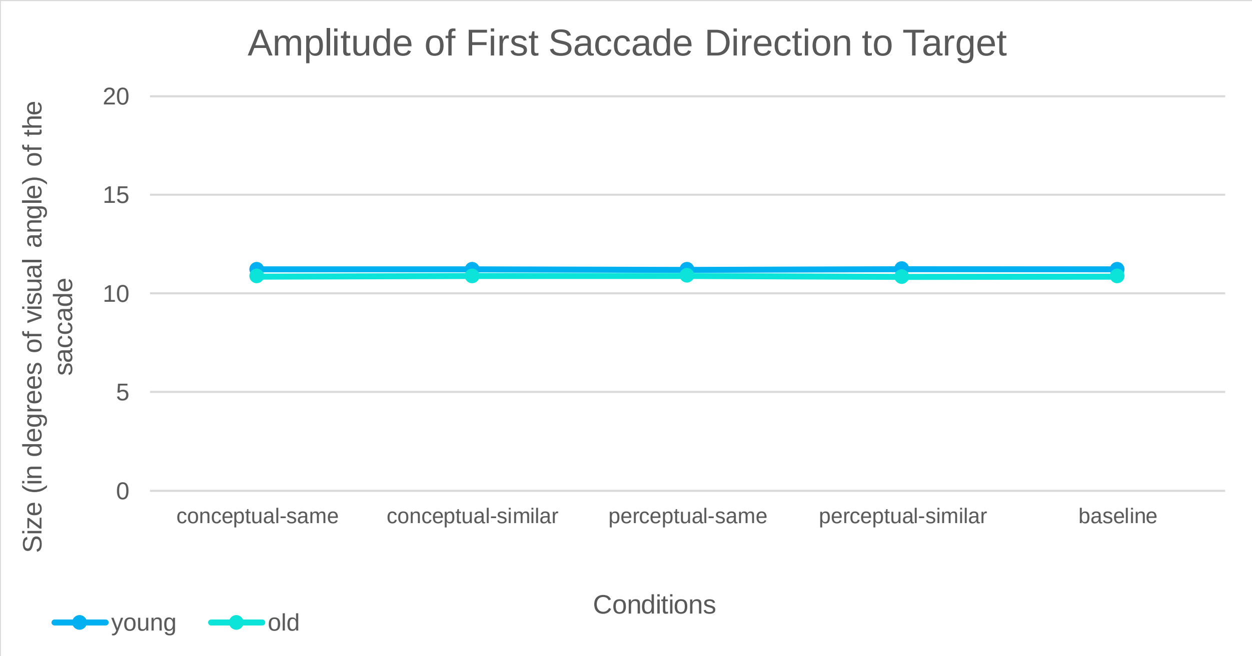
Amplitude of first saccades

Arriving Directly to the Target Object

Next, considering the analyses of the amplitude of first saccades that arrived to the target object. A repeated measures ANOVA found no effect of Relational Level, $F(4, 192) = 0.062$, $p = 0.993$, $\eta^2_p = 0.001$, $BF_{10} = 0.012$, or interaction with age, $F(4, 192) = 0.874$, $p = 0.480$, $\eta^2_p = 0.018$, $BF_{10} = 0.125$. There was an overall age group effect, $F(1, 48) = 10.539$, $p = 0.002$, $\eta^2_p = 0.180$, $BF_{10} = 10.109$, with YAs demonstrating the highest amplitude with saccades arriving first to the target. See Figure 28 below for a visualization of both young and older adults of the amplitude of first saccades that went to the target object.

Figure 28

Young and Older Adults' Amplitude of First Saccade to Target Object in Eye-tracking Experiment



Arriving Directly to the Target Object and Target Area

Following this I then conducted an analyses of the amplitude of the first saccades that arrived to the target object and the target area. A repeated measures ANOVA found no effect of Relational Level, $F(3.213, 154.220) = 1.163$, $p = 0.327$, $\eta^2_p = 0.024$, $BF_{10} = 0.66$, or interaction with age, $F(3.213, 154.220) = 1.088$, $p = 0.358$, $\eta^2_p = 0.022$, $BF_{10} = 2.746$. There was an overall age group effect, $F(1, 48) = 14.576$, $p < 0.001$, $\eta^2_p = 0.233$, $BF_{10} = 44.299$, with YAs demonstrating the highest amplitude with saccades arriving first to the target and target area.

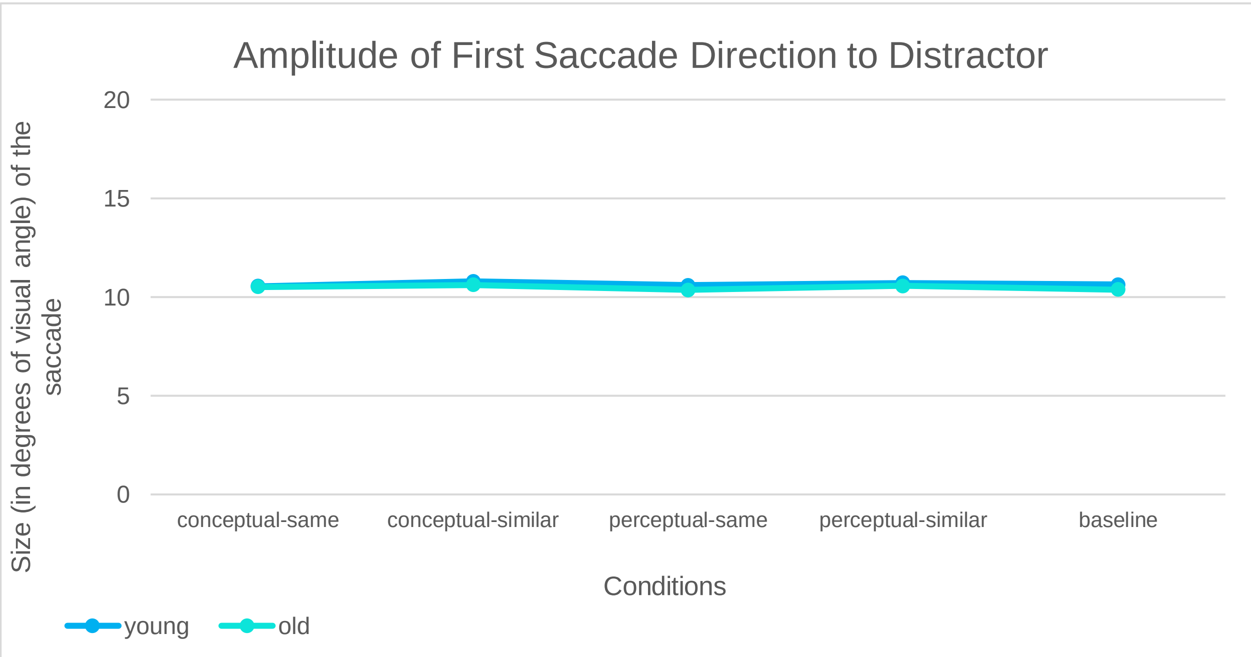
Arriving Directly to the Distractor Object

Next, I analyzed the amplitude of the first saccades that arrived to the distractor object. For this analysis, similar to the velocity and duration analyses of the first saccade directed towards the distractor, four of the YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found an effect of

Relational Level, $F(4, 176) = 3.483$, $p = 0.009$, $\eta^2_p = 0.073$, $BF_{10} = 3.120$. However, Post Hoc follow-up analyses found the Relational Level conditions to not be significantly different from one another, with the exception of the conceptual similar condition and the baseline condition ($p = 0.0216$). There was no age group interaction with Relational Level, $F(4, 176) = 0.731$, $p = 0.572$, $\eta^2_p = 0.016$, $BF_{10} = 2.388$, or an overall age group effect, $F(1, 44) = 2.259$, $p = 0.140$, $\eta^2_p = 0.049$, $BF_{10} = 0.765$. See Figure 29 of both young and older adults of the amplitude of first saccades that went to the distractor object.

Figure 29

Young and Older Adults' Amplitude of First Saccade to Distractor Object in Eye-tracking Experiment



Arriving Directly to the Distractor Object and Distractor Area

Next, I analyzed the amplitude of the first saccades that arrived to the distractor object and area. For this analysis, four of the YAs had to be removed as they did not have enough responses of arriving to the distractor. A repeated measures ANOVA found no significant effect of Relational Level, $F(2.703, 118.919) = 2.164$, $p = 0.102$, $\eta^2_p = 0.047$, $BF_{10} = 0.431$, of age, $F(1, 44) = 1.604$, $p = 0.212$, $\eta^2_p = 0.035$, $BF_{10} = 0.596$, or of their interaction, $F(2.703, 118.919) = 1.253$, $p = 0.293$, $\eta^2_p = 0.028$, $BF_{10} = 0.263$.

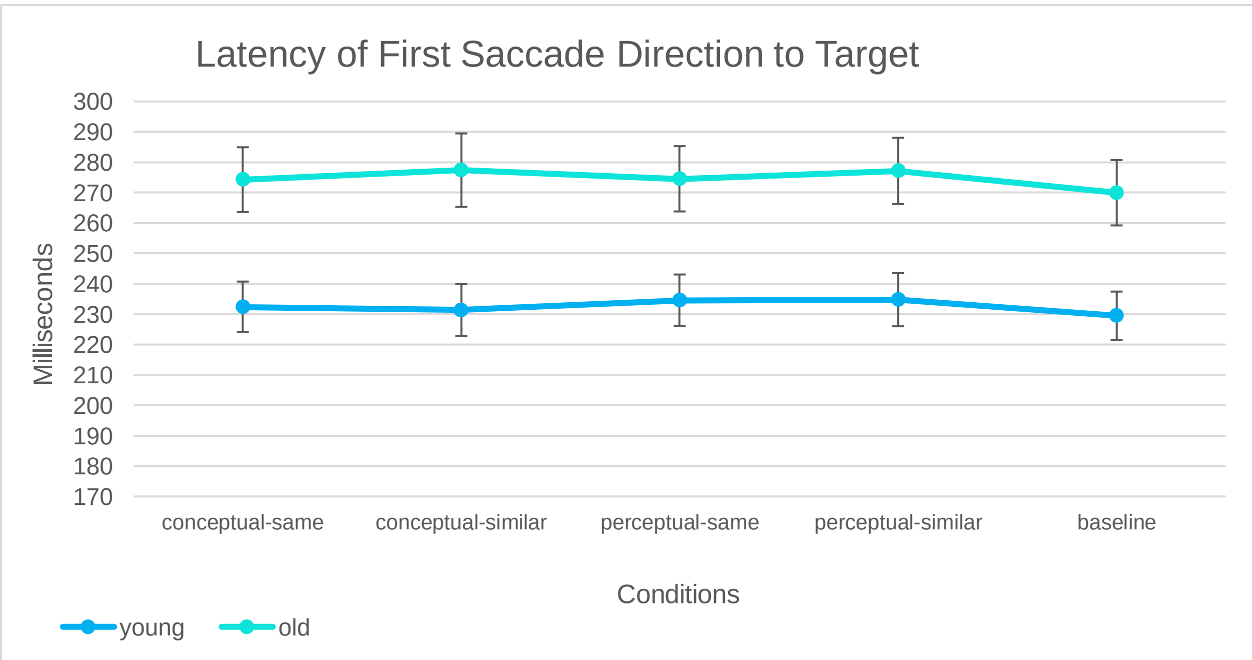
Latency of first saccades

Arriving Directly to the Target Object

The proceeding analyses was to compare the latency of the first saccades towards the target. A repeated measures ANOVA found no effect of Relational Level, $F(4, 192) = 2.341$, $p = 0.057$, $\eta^2_p = 0.47$, $BF_{10} = 0.432$, or interaction with age, $F(4, 192) = 0.612$, $p = 0.655$, $\eta^2_p = 0.013$, $BF_{10} = 2.654$. There was an overall age group effect, $F(1, 48) = 9.603$, $p = 0.003$, $\eta^2_p = 0.167$, $BF_{10} = 6.600$, with OAs demonstrating the highest latency of first saccades arriving to the target object. See **Figure** ***30*** below for a visualization of both young and older adults depicting the latency of first saccades that went to the target object.

Figure 30

Young and Older Adults' Latency of First Saccade to Target Object in Eye-tracking Experiment



Arriving Directly to the Target Object and Target Area

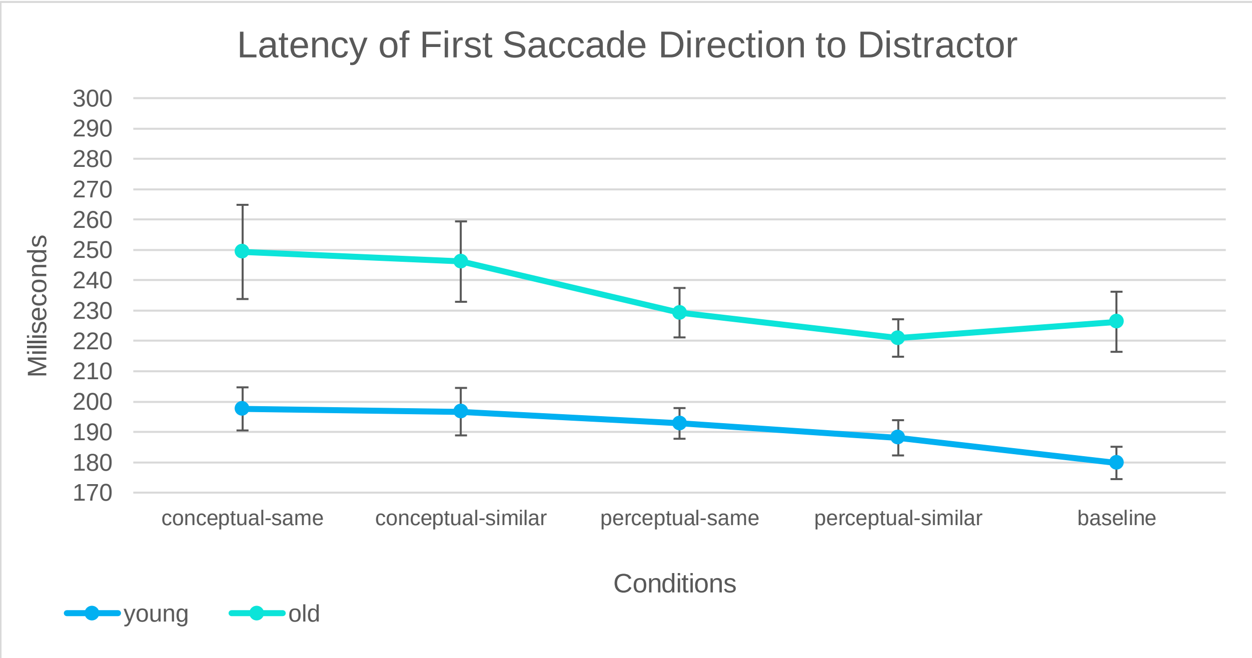
Next, I wanted to compare the latency of the first saccades towards the target and the target area. A repeated measures ANOVA found no effect of Relational Level, $F(4, 192) = 0.643$, $p = 0.632$, $\eta^2_p = 0.013$, $BF_{10} = 0.030$, or interaction with age, $F(4, 192) = 0.458$, $p = 0.766$, $\eta^2_p = 0.009$, $BF_{10} = 0.071$. There was an overall age group effect, $F(1, 48) = 6.422$, $p = 0.015$, $\eta^2_p = 0.118$, $BF_{10} = 1.754$, with OAs demonstrating the highest latency of first saccades arriving to the target and target area.

Arriving Directly to the Distractor Object

Next, I wanted to compare the latency of the first saccades towards the distractor object. Again, for this analysis, four YAs had to be removed for not having enough first saccades arriving to the distractor object. A repeated measures ANOVA found an effect of Relational Level, $F(2.913, 128.164) = 5.126$, $p = 0.002$, $\eta^2_p = 0.104$, $BF_{10} = 56.001$. Post Hoc analyses found the conceptual same condition ($p = 0.01$) to be significantly different from baseline and conceptual similar significantly different from baseline ($p = 0.005$). There was no interaction between age and Relational Level, $F(2.913, 128.164) = 0.990$, $p = 0.398$, $\eta^2_p = 0.022$, $BF_{10} = 4044.496$. There was an overall age group effect, $F(1, 44) = 14.978$, $p < 0.001$, $\eta^2_p = 0.254$, $BF_{10} = 71.482$, with OAs demonstrating the highest latency of first saccades arriving to the distractor object. See Figure 31 below for a visualization of the latency of first saccades that went to the distractor object for young and older adults.

Figure 31

Young and Older Adults' Latency of First Saccade to Distractor Object in Eye-tracking Experiment



Arriving Directly to the Distractor Object and Distractor Area

Finally, I compared the latency of the first saccades towards the distractor and the distractor area. For this analysis, four YAs had to be removed for not having enough first saccades arriving to the distractor object. A repeated measures ANOVA found an effect of Relational Level, $F(2.735, 120.357) = 3.383$, $p = 0.024$, $\eta^2_p = 0.071$, $BF_{10} = 3.846$. Post Hoc analyses found the conceptual same condition to be significantly different from baseline (p = 0.04). There was no age group interaction with Relational Level, $F(2.735, 120.357) = 1.487$, $p = 0.224$, $\eta^2_p = 0.033$, $BF_{10} = 15.309$. There was an overall age group effect, $F(1, 44) = 6.495$, $p = 0.014$, $\eta^2_p = 0.129$, $BF_{10} = 3.708$, with OAs demonstrating the highest latency with first saccades arriving to the distractor and distractor area.

5.3 Experiment 5 Discussion

The main aim of the current study was to implement oculomotor measurements in order to examine whether there are differences in the manner in which OAs assess real-world objects, potentially dependent on the features (conceptual and perceptual) of the objects. Overall, OAs demonstrated longer RTs in arriving at the target image, however this was not dependent on the relational level (conceptual or perceptual) of the conditions. Additionally, the amount of first saccades that went to the target object or the distractor object was significantly different between the groups: OAs were less likely to first view the target object, and more likely to first view the distractor object. This finding overall, suggests that OAs are less efficient in detecting a target, and more likely to view distractors. Imperatively, both effects are not qualitative, as these age-effects did *not* depend on the condition type of the distractor object. Moreover, these age-effects were also supported by Bayesian factor analysis, which suggested support for the alternative hypothesis.

The finding of OAs viewing more frequently the distractor object is possibly the result of a declined useful field of view (UFOV) in aging (Sekuler, Bennett, & Mamelak, 2000**;** Veiel et al., 2006). In line with this logic, it is possible that OAs were more prone to direct their first saccade at the distractor objects, possibly as a result of a declined UFOV (Sekuler, et al., 2000; although see discussion of Kramer et al., 1999), and therefore necessitating an initial direction in their vision to confirm the distractor object is not the target..

Next, considering the velocity, duration, amplitude, latency measurements of first saccades, I found a few significant differences between the age groups overall. First, the duration of first saccades to the distractor (as well as the combined distractor and distractor area) was longer for OAs. Next, for latency measurements, OAs had an overall higher latency for first saccades going to the target (as well as target and target area combined) and for first saccades arriving at the distractor (as well as the additional combined analyses of distractor and distractor area). Alternatively, the velocity of going to both combined object and object areas (combined target object and area as well as the distractor and distractor area) were highest in YAs. This finding further reinforced the point that OAs were slower in their eye movements further reflecting the RT analyses. Overall, however, these age-effects did not interact with the relational level of the conditions. In sum, although overall slower, OAs were not disproportionately slower in arriving to their assessment of the distractor or target object dependent on the features of these objects. These results suggest overall, a general slower processing speed in OAs (Salthouse, 2012).

In terms of these results compared to previous aging and eye movement studies, Kramer et al. (1999) found in their study that OAs and YAs were similarly impacted by the presence of a task-irrelevant distractor. Kramer et al. (1999) crucially also implemented control trials without a task-irrelevant stimulus however and found OAs had poorer saccade accuracy, suggesting there is a general impairment in aging of saccade accuracy, although this did not interact with the task-irrelevant stimuli. This finding corresponds with the finding of the current study, essentially, OAs were less accurate, but this is not dependent on task-irrelevant stimuli presentation (Kramer et al., 1999) or distractor featural characteristics, as suggested by the findings of the current study.

Furthermore, it is important to note that Dennis et al. (2004) found age-related differences in the influence of color similarity “contrast polarity” (Dennis et al., 2009). Furthermore, in Williams et al. (2009), the researchers found both age groups to view the category distractors in their study the most frequently (after targets), and OAs for disproportionately longer. Considering these differing findings with respect to the current study, it is possible that the lack of an age effect in the current study may be the result of the small amount (two) of objects in the display, in opposition to both Dennis et al. (2009) and Williams et al. (2009) that presented 7, 13, 19 and 12 objects, respectively. In the aforementioned studies, it is possible that in these previous studies, as participants had more time to assess the display (main objective was for the participant to find their stimuli), this picked up on age-effects in the assessment of the objects. Alternatively, in the current study, I measured the initial attentional capture of the presentation of the two stimuli. It would be interesting to expand the current study with the given stimuli and relational level conditions of interest, and explore whether age-effects are present when OAs and YAs are asked to search the display for the presence or absence of their target, in a similar fashion to the visual search tasks presented in Chapter 4.

Moreover, for both OAs and YAs, the baseline condition led to more instances of the first saccade arriving directly to the target object, compared to the other four conditions where target and distractor were similar in either perceptual or conceptual features. As a reminder, the baseline condition was comprised of a distractor object that did not belong to either the same category or color as the target. This result suggests, regardless of age, distractors that share perceptual or conceptual features with the target are difficult to ignore. Whereas, when there is a distractor object with two features (color and category) that are different from the target, both age groups are sufficient at ignoring this object.

An interesting next analysis would be to examine possible “corrections” of eye movement trajectories. For example, it could be possible that YAs went to the distractor area (not arriving all the way to the distractor object) and then “corrected” their trajectory to then go to the other side, corresponding to the location of the target object. This correction behavior could have occurred due to YAs peripherally detecting on their trajectory to the distractor side of the screen that that distractor object was not their target, and then they accordingly corrected trajectory. An interesting analysis would be to examine whether these corrections occur more in YAs. It is possible OAs may be more likely to arrive to the distractor to confirm that it is not their target. This possibility follows from suggestions of more "conservative" approaches in aging in visual search (see Dennis et al., 2004) and the declining UFOV in aging (Sekuler, et al., 2000) as OAs may be less likely to peripherally detect the dissimilar features of the distractor object. Although there were not enough trials in the individual relational level conditions to conduct this analysis, if condition was collapsed for, one could simply explore possible age-differences in corrections.

In the consideration of OA's vWM and attention abilities, utilizing eye movement measurements can provide an indication of age-related cognitive declines (see Wynn et al. 2020). Overall, the findings of the current study suggest OAs are more likely than YAs to take longer to initiate eye movements and initially look at the distractor object. Focusing more on assessing oculomotor behaviors in aging could be informative in adding to our understanding of attention declines in aging. Moreover, this type of measurement is being used more frequently in populations with both mild cognitive impairment and Alzheimer's disease and Parkinson's disease, therefore, developing a comprehensive understanding of the trajectory of eye movement behavior across the trajectory of life is an imperative consideration (Cimminella et al., 2022; Coco, Merendino, Zappalà, & Della Sala, 2021; Coco, Maruta, Martins, & Sala, 2022; Fooken et al., 2022; Ionescu et al., 2023).

Chapter 6

Summary and General Discussion

6.1 Summary

The aging population is steadily increasing (WHO, 2022), hence it is important to understand the cognitive profile that encompasses older age. Two cognitive domains, visual working memory (vWM) and attention, are known to be impacted throughout the discourse of aging (Naveh-Benjamin & Cowan, 2023), although it is not always the case that older adults (OA) demonstrate difficulties in these domains (Souza et al., 2023; see Holcomb et al., 2022 for a review in vWM and age-effects). Accordingly, a comprehensive understanding of age-effects within the scope of these two cognitive functions is imperative.

An under-researched topic in the cognitive aging field is the influence of the content of items versus only the amount of items in determining OA's performances. Therefore, the first aim of this thesis project was to investigate the possible influence of the object content of representations in conjunction with the amount, in determining OA's vWM and attention performances. The majority of research in this field has used geometrical stimuli for investigations on vWM and attention abilities in aging, however, less is known with regards to how OAs perform when real-world objects are the stimuli. Accordingly, the second aim of this thesis project was to examine whether the traditional finding in the vWM and attention in aging field extends when real-world objects are used. The implementation of real-world objects is important given the higher applicability to real-world situations, and allows for the question of object content versus the amount to be examined further in the current thesis project. This examination has been limited when using geometrical stimuli (although see Chapter 2), however when real-world objects are implemented, one can examine not only whether simple features are the determinants of vWM capacity, or attentional demands, but instead whether the representational content (here investigated through different manipulations of perceptual and conceptual similarity) interacts with the amount of objects presented.

In sum, the main questions addressed in this thesis project were to a) explore the possible influence of the nature of object representations, either in interacting with object numerosity (**Chapters 2-4**) or alone (**Chapter 5**), on cognitive aging. The second aim of this thesis project was to study this using real-world objects, due to the high applicability to everyday life.

In Chapter 2, I presented a mini-review on feature binding in vWM in aging. Feature binding investigations are imperative within the discussion of content and amount in determining OA's performances as these studies investigate above and beyond how many items are retained by OAs, but probe also the quality of these representations. Feature binding investigates this topic through examining whether participants are able to retain and recall the bound representation within one item comprised of more than one feature (i.e., within-object feature binding), or which item was presented in which position in a display (object-to-location binding). It is important to note as well, that the discussion of feature binding does not only concern vWM but also attention, as attention is required in order to form the bound representation (within-object or object-to-location) either in general (Treisman & Gelade, 1980) and also specifically in aging (see Brown & Brockmole, 2010). Accordingly, age impairments in feature binding may be the reflection of either attention declines or vWM (or both). The main take-away message from the studies presented in Chapter 2 was that object-to-location binding (the bound representation of an object to its location) may be impaired in aging. I argue in the mini-review that future studies in the cognitive aging field should manipulate both aspects: content (through means of feature binding) and amount of items, in order to investigate the question of whether vWM is limited only by the amount or is limited in conjunction with the content as well.

As reported in Chapter 2, most of the studies on the effect of content representation in age-related decline (either in interaction with object numerosity or not) relied on geometrical shapes (Brown & Brockmole, 2010; Cowan et al. 2006; Parra et al. 2009; Rhodes et al. 2016), or line drawings (Mitchell et al., 2000a). In contrast, using real-world objects as stimuli allows different features to be manipulated for the sake of measuring a qualitative influence on performances. In the experiments described in this thesis, I considered the perceptual and conceptual features of real-world objects. The motivation for considering the conceptual and perceptual features was to examine whether the features differentially impact OA's performances (suggesting qualitative differences). Moreover, I choose to examine the influence of these features through manipulating the similarity in these two aspects as a proxy for examining the qualitative influence of object representations.

In Chapter 3, I conducted two experiments investigating OA's vWM performances whilst performing a change detection task (CDT) in which conceptual and perceptual similarity was manipulated between the objects. The additionally important manipulation in Chapter 3 was the amount (object numerosity) of the items presented. In Experiment 1 of Chapter 3, the similarity of the real-world objects was manipulated in terms of their conceptual similarity (high or low) and in Experiment 2, the similarity of the real-world objects was manipulated in terms of their perceptual similarity (high or low). Importantly, item numerosity was also manipulated in both experiments with either 2 or 3 items presented.

First, the main question being addressed in Experiment 1 was whether there was an interaction between age and the characteristics of the objects presented either low or high in conceptual similarity, and whether this factor additionally interacted with the amount of items presented. Secondly, the main question addressed in Experiment 2 was whether there was an interaction between the objects presented that were either low or high in perceptual similarity with the other items presented, and whether this factor interacted with the amount of items presented. Both age groups performed similarly in these experiments, suggesting that OAs are able to maintain similar change detection (CD) performances as young adults (YA), both in the quality of the representations and in the amount. This latter finding of lack of worse performances in aging with more items is in opposition to findings of Peich et al. (2013) and Pertzov et al. (2015), also using smaller set sizes (1 and 3 items). Possible reasonings for the lack of a significant age-effect in Chapter 3 were discussed at length in the General Discussion of Chapter 3 and will be discussed in the Limitations and Future Directions section below.

In **Chapters 4** and **5** I examined another domain that has been shown to decline with aging (Naveh-Benjamin & Cowan, 2023), namely attention. Research in this area has additionally indicated that the age-related cost in attention is exacerbated when items are highly similar (Plude & Doussard-Roosevelt, 1989; Scialfa et al., 1998). Thus, the aim of the experiments in Chapter 4 and Chapter 5 was to examine aging performances when real-world objects are the stimuli of interest and attention is required. I investigated this question with a two-fold approach: 1) first, through manual responses (**Chapter 4**) then, 2) through measuring ocular movements (**Chapter 5**). The first investigation (Chapter 4) allowed me to also investigate the interaction between target-distractor similarity and item numerosity. Furthermore, with the assessment of eye movements in Chapter 5, possible subtle effects in the nature of object representations in capturing OA's attention may be captured.

In Chapter 4, I implemented two experiments manipulating both the perceptual and conceptual similarity between distractors and a target to search for the presence or absence of in a visual search task (VST) display. In Experiment 3 of Chapter 4, I included a smaller set size of objects presented in the display (5, 7 and 10 objects), while in Experiment 4, I increased the set size to 10, 12 and 15 objects. While in Experiment 3 the age-effects were minimal, Experiment 4 found a significant age increase in reaction times in each of the similarity conditions, suggesting an imperative influence of a cluttered display in influencing how OAs efficiently assess a display. In sum, I provided evidence that the only imperative determinant to OA's decrease in performances was a higher amount of objects presented in the display, not the perceptual or conceptual relation between the objects. While I found that both OAs and YAs were impacted be the perceptual similar conditions, this effect was not exacerbated by aging. Possible limitations of this study are discussed below (Limitations).

In Chapter 5, I also assessed age-related attention behavior by implementing an eye-tracking experiment in which OAs and YAs were asked to direct their eyes towards a pre-defined real-world target object. In this experiment, another object was presented on the opposite side of the screen, which the participant needed to ignore. This additional object (a distractor) was perceptually or conceptually similar to the target. The main question that was investigated in Chapter 5 was whether there were age differences in the attentional and visual capture of distractor images overall, and whether this additionally interacted with the type of image manipulation (perceptual or conceptual), in capturing attention. Moreover, in addition to the perceptual and conceptual manipulations of real-world objects in Chapter 3 and Chapter 4, in Chapter 5 I also included two levels of both of these manipulations: 1) perceptually similar to the target (a color slightly similar, i.e., gray and black), 2) perceptually identical to the target (the same color), 3) conceptually similar to the target (same type of object but a different image, i.e., different types of shirts) and 4) conceptually identical to the target (the same image type, i.e., same shirt). However, despite these higher "levels" of manipulations in Chapter 5, I found no age differences in the type of image, in capturing attention. I did find however that OAs were overall slower in their eye movements, reflected both in RT analyses, as well as velocity and duration saccade analyses. Moreover, OAs made fewer first saccades towards the target and more first saccades to the distractors compared to YAs. Both groups were distracted more by the four similarity conditions, relative to the baseline condition, however this effect was not modulated by age. Overall, these results suggest that although OAs are more distracted and slower, these effects on oculomotor behaviors are not the result of a differential assessment of the characteristics of the objects.

6.2 Limitations and Future Directions

A limitation that could apply to the experiments in both Chapter 3 and Chapter 4 pertains to the possibility that OAs developed a strategy throughout the duration of the experiment, that then ameliorated any age-effects that otherwise would be present. Possible strategies could range from using the shape of the objects, instead of individuating and maintaining each object, as well as taking a "snapshot" of the display. Both of these strategies would have been more useful in the experiments described in Chapter 3, related to the CDT. However, the use of the shape of an object, as opposed to appropriately individuating the object itself, is a strategy that could have proved useful in the experiments presented in Chapter 4 as well. As discussed in the General Discussion of Chapter 3, it has been previously found that OAs are capable of employing attentional control as well as benefiting from the context of the display, in order to aid their performances (Mok, et al., 2016; Mitchell et al., 2018), or develop semantic associations to aid their performances (see Wiegand & Wolfe, 2020). This could have occurred either in the participant memorizing only the outline of the target object presented at the start of the block, and subsequently only searching for those with a similar shape, as well as in the fast rejection of any object in the visual search display that did not have the same shape as the target object in memory. Moreover, an additional possibility that is worth noting is work done in YAs that suggest more realistic scenes and ecological contexts may lead to better visual WM performances (Kristjánsson & Draschkow, 2021 see also Kaiser, Quek, Cichy, & Peelen, 2019). Future research should further investigate this to probe these possible effects in aging as well. Interestingly, Kristjánsson and Draschkow (2021) present a review discussing the use of natural tasks (real-world settings for example) and the researchers discuss that the guidance of attention can be determined by long-term episodic and semantic memory. Moreover, the researchers also suggest long and short-term representations can circumvent capacity limitations in WM. Is it possible that when more naturalistic stimuli are used also OAs are able to bypass the commonly found age-effects in attention and WM tasks (such as found in the current thesis)? Wiegand and Wolfe (2020) suggest the reasoning for minimal age-effects found in their recent hybrid memory-visual search experiment to possibly be due to rich semantic associations and target representations that OAs were able to form with the real-world objects utilized in their experiment. It is possible that also in the current studies, OAs compensate for declining memory or attention abilities through making semantic associations of the stimuli, possibly circumventing effects that would have been present if the stimuli were simpler.

Finally, it is important to consider whether the OAs in each of the experiments are outliers from the general OA population, in the sense that typically those who participate in experiments are quite cognitively active and proficient. This point is especially relevant for the experiments conducted in Chapter 3 and Chapter 4, as these studies were conducted online. It is possible that any OA individual that is active in an online platform for research and enroll in research experiments, may be a cognitive outlier compared to the general population within their age group. Furthermore, as a good portion of the subjects recruited (both in the online studies and for the in-person eye-tracking experiment) were participants from previous studies in our research group, these participants are generally accustomed to experimental procedures.

In order to account for the above limitations better, future research could first implement a change detection localization task, in order to control for the possible strategies utilized (shape or a "snapshot" of the display) in Chapter 3. In this type of a task, the final screen could either contain the probe object in the same position, presented without the other objects from the memory display, or the object in the center of the screen. An additional manipulation, also assessing object-to-location feature binding (see Chapter 2), could be to implement the dual response features utilized in Pertzov et al. (2015), probing subjects to select the previously presented object from the center of the display, and subsequently drag the object to its' previously presented location. Overall, presenting either only one or two objects (but not in their previously presented locations), circumvents the possible technique of reliance on a "snapshot" of a display.

Secondly, an additionally interesting experiment would be to implement an eye-tracking study with the same VSTs presented in Chapter 4. This type of an experiment could give a useful indication of the amount of time looking at each distractor object, whether this is dependent on the characteristic of the object (conceptual or perceptual), and if this interacts with age.

Finally, an additional limitation of the current thesis worth delineating concerns the implementation of the stimuli set used. Considering the categories used, it would have been additionally beneficial to implement a norming study in order to confirm the degree of similarity that participants assessed as the distinction between these four categories. This point is important and should be considered in future studies, as some of the categories may have been assessed by participants as more "similar" than others. Secondly, considering the perceptual similarity manipulations, it would have also been beneficial to conduct a control analysis a prior of the perceptual similarity manipulations (Experiments 2-5). Although these stimuli were each edited into defined color groups, research has indicated the importance of considering visual saliency of stimuli, either objects or scenes (Itti & Koch, 2000; Walther, Itti, Riesenhuber, Poggio, & Koch, 2002), that is not only dependent on color. A post-hoc color saliency analysis was conducted of the stimuli used in Experiments 2-4 (see 3.3.2 Stimuli and Apparatus and Appendix B for results), and the rationale of this analysis was to ensure that the color perceptual similarity as manipulated in Experiments 2-4 was independent of the perceptual (color) salience of the experiment display. Additionally, the rationale was to investigate whether this salience was independent as well of the high and low similar conditions (Experiment 2), that may have led to differences aside from these experiment manipulations. This, as well as computing additional visual saliency metrics, is an important consideration for future studies as it is possible not only the color similarity could influence participants' assessment of perceptual similarity conditions.

6.3 Concluding remarks

Overall, this thesis project addressed whether the traditional vWM and attention in aging findings extend when real-world objects are the stimuli used. Moreover, this thesis also addressed whether the content (through means of conceptual and perceptual similarity) of real-world objects has an additive effect on OA's performance with respect to their numerosity, or alone. Inclusively, I found minimal age-effects across the studies implemented. A possible interpretation of the slight reductions in performances of OAs found in the experiments described in my thesis could be the result of age-related slowing (Salthouse, 1996), not necessarily the result of specific age impairments. Importantly, although OAs appear to be slower and less accurate in some instances, this effect is not mediated by the representational content of the objects, in the sense that the perceptual or conceptual nature of the objects did not have a differential detrimental (or beneficial) impact on OAs' performances with respect to the younger controls. As mentioned in the beginning, in aging, it has been suggested that not all aspects of vWM and attention are impaired (Souza et al., 2023; Holcomb et al, 2022), and the findings of this thesis project overall support these conclusions.

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Appendices

Help with the analyses of the pilot studies described below was carried out by Rodolfo Rizzi for his work in our group as a Bachelor's student.

The stimuli set used for **Experiments 1, 2, 3** and **4** included 72 base images from the Aude Oliva "Object categories" repository (Konkle et al., 2010). In **Experiment 1**, each of the 72 images were also re-used as a probe change in the test array, resulting in 144 images in total: 72 for the memory array and 72 for the test array.

Appendix A: Experiment 1 Change Detection Task with Conceptual Similarity Stimuli Details

There were four object categories: 1) Tools / Appliances, 2) Furniture, 3) Cook / Tableware and 4) Clothing. There were two sub-categories in each of these four supra-categories (see **Table A1** (column name: **sub-category-labels**)). Within each category, there were six total image item types (axes, for example), subdivided into each of the two sub-categories, with three in each sub-category. Each image item type (i.e., axes) had three exemplars, for example there were three different axe images (named accordingly: axe 1, axe 2, axe 3).

Importantly to note, the change image presented in the test array was the same color as the original image, and in some instances, this image was edited in Adobe Photoshop to match the color as the image it was "replacing" in the test array. See **Table A1** below for RGB ranges of both original memory array images and test array probe images.

Next, in some instances, the original or probe image was also oriented in Photoshop. Image types that had the orientation changed were flashlights, gloves, hammers and axes. The main motivation for this orientation change was to have the same orientation between the original and probe images.

For example, "axe 2" in **Figure 1A** was presented in the memory array and the following image presented in the test array would be the black flashlight (on change trials). In this situation, the flashlight image on the right was oriented upright. Alternatively, when the flashlight image was used as an original image in the memory array (**Figure 2A**), it was presented at the orientation in **Figure 2A**.

Appendix Figure 1A

Memory Array Image to Test Array Image Probe Change Example from Experiment 1

Appendix Figure 2A

Image Orientation Example from Memory Array

It is also important to note the categorization of the base images were tested in pilot studies. In the pilot studies, "Gloves" and "flashlights" were presented at a horizontal position and "hammers" at a slightly turned position (at the orientation as downloaded from original database), however in this experiment, they were then oriented to be upright.

Finally, in this experiment, the name of the change image presented in the test array would be the name of the image it was replacing with a "c" at the end ("change"). Take for example the flashlight image replacing the axe 2 image in **Figure A1**, the axe (original image) name is "axe2" therefore the flashlight that is replacing the axe in the test array would be named "axe2c". When this particular flashlight was an original image (presented in the memory array) as in **Figure 2A**, it had its' original name of "flashlight 1". In the following **Table A1** the stimuli details for **Experiment 1** are listed. Column: **Stimulus File** contains the name of each of 72 base images used. Importantly, the names of the images are those that I assigned for cohesion in use in my experiments, they do not correspond to the image names on the Aude Oliva image database (Konkle et al., 2010). In **Table A1**, the column: **Category** corresponds to the numeric number of the category of the image (1-4), while **Category_labels** are the written text for those categories. Next, **Subcategory** is the subcategory (1 or 2) within the overall supra-category, and the **Subcategory_labels** are the written text for those sub-categories.

Next, in the **Color_Stimulus File** column, there are the RGB values listed of the stimulus image. The column: **Conceptual_Change** is the name of the probe image that this stimulus file would change into on change trial conditions, and the next column: **Originally** is the original name of this change image. An example: if the **Stimulus_file** name was "axe 2", "axe2c" would be the **Conceptual_change** name and in the **Originally** column, the name would be "flashlight1".

Finally, in the **Item** column, this is the type of image that this image is: an axe, a flashlight, and so forth. In the **Color_Conceptual_Change** column there are the RGB values listed for the change images.

Table 1A

Experiment 1 Image List and Details

STIMULUSFILE	CATEGORY	CATEGORY _labels	SUBCATEGORY	SUBCATEGORY_labels	Color_Stimulus File	CONCEPTUAL_CHANGE	ORIGINALLY	ITEM	COLOR_Conceptual_Change
axe1.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0275-1, 0.5020-1, 0.5059-1	axe1c.jpg	fan1.jpg	Axe	RGB: 0.1059-1, 0.2000-1, 0.2431-1
axe2.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0039-1, 0.0039-1, 0-1	axe2c.jpg	flashlight1.jpg	Axe	RGB: 0.0039-1, 0.0039-1, 0039-1
axeoption1.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.4314-1, 0.3490-1, 0.2235-1	axeoption1c.jpg	washer1.jpg	Axe	RGB: 0.3529-1, 0.3098-1, 0.2588-1
bowl1.jpg	3	Cook and Tableware	1	Eating	RGB: 0.0235-1, 0.0863-1, 0.2510-1	bowl1c.jpg	coffeemug1.jpg	Bowl	RGB: 0.1137-1, 0.1451-1, 0.2627-1
bowl2.jpg	3	Cook and Tableware	1	Eating	RGB: 0.0745-1, 0.0784-1, 0.0667-1	bowl2c.jpg	pitcher3.jpg	Bowl	RGB: 0.4706-1, 0.4667-1, 0.4706-1
bowl3.jpg	3	Cook and Tableware	1	Eating	RGB: 0.2510-1, 0.0118-1, 0.0275-1	bowl3c.jpg	wineglass2.jpg	Bowl	RGB: 0.2863-1, 0.0275-1, 0.0275-1
bowtie1.jpg	4	Clothing Items	2	Accessories	RGB: 0.4627-1, 0.0078-1, 0-1	bowtie1c.jpg	long-sleevedshirt1.jpg	Bowtie	RGB: 0.1490-1, 0.0353-1, 0.0353-1
bowtie2.jpg	4	Clothing Items	2	Accessories	RGB: 0-1, 0.1176-1, 0.0039-1	bowtie2c.jpg	pants2.jpg	Bowtie	RGB: 0.0863-1, 0.2157-1, 0.1412-1
bowtie3.jpg	4	Clothing Items	2	Accessories	RGB: 0.1098-1, 0.1882-1, 0.2863-1	bowtie3c.jpg	shirt1.jpg	Bowtie	RGB: 0.1686-1, 0.2471-1, 0.3216-1
chair1.jpg	2	Furniture	1	Seating	RGB: 0.3647-1, 0.2784-1, 0.1843-1	chair1c.jpg	dresser3.jpg	Chair	RGB: 0.6745-1, 0.5490-1, 0.4118-1
chair2.jpg	2	Furniture	1	Seating	RGB: 0.0039-1, 0.0039-1, 0.0784-1	chair2c.jpg	table2.jpg	Chair	RGB: 0.0-1, 0.1137-1, 0.1451-1
chairoption1.jpg	2	Furniture	1	Seating	RGB: 0.0431-1, 0.0627-1, 0.0275-1	chairoption1c.jpg	desk1.jpg	Chair	RGB: 0.3255-1, 0.3529-1, 0.2980-1
coffeemug1.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.3882-1, 0.1137-1, 0.2000-1	coffeemug1c.jpg	bowl1.jpg	Coffee Mug	RGB: 0.5137-1, 0.1529-1, 0.3686-1
coffeemug2.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.5412-1, 0.3098-1, 0-1	coffeemug2c.jpg	spoon1.jpg	Coffee Mug	RGB: 0.62745-1, 0.3922-1, 0.1333-1
coffeemug3.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.2039-1, 0.2039-1, 0.2039-1	coffeemug3c.jpg	pan3.jpg	Coffee Mug	RGB: 0.1725-1, 0.1725-1, 0.1725-1
deckchair1.jpg	2	Furniture	1	Seating	RGB: 0.4275-1, 0.2863-1, 0.1804-1	deckchair1c.jpg	desk3.jpg	Deck Chair	RGB: 0.4039-1, 0.3098-1, 0.2078-1
deckchair2.jpg	2	Furniture	1	Seating	RGB: 0.3255-1, 0.1176-1, 0.0314-1	deckchair2c.jpg	dresser2.jpg	Deck Chair	RGB: 0.1490-1, 0.0941-1, 0.0588-1
deckchair3.jpg	2	Furniture	1	Seating	RGB: 0.1490-1, 0.1882-1, 0.2235-1	deckchair3c.jpg	table1.jpg	Deck Chair	RGB: 0.0980-1, 0.2078-1, 0.2745-1
desk1.jpg	2	Furniture	2	Non-Seating	RGB: 0.3333-1, 0.2275-1, 0.1412-1	desk1c.jpg	chair1.jpg	Desk	RGB: 0.2431-1, 0.1804-1, 0.0902-1
desk2.jpg	2	Furniture	2	Non-Seating	RGB: 0.5451-1,	desk2c.jpg	deckchair3.jpg	Desk	RGB: 0.5373-1, 0.2431-1, 0.2235-1

					0.2745-1, 0.2118-1				
desk3.jpg	2	Furniture	2	Non-Seating	RGB: 0.1686-1, 0.1020-1, 0.0353-1	desk3c.jpg	sofa1.jpg	Desk	RGB: 0.1216-1, 0.0941-1, 0.0706-1
dresser1.jpg	2	Furniture	2	Non-Seating	RGB: 0.2863, 0.1098-1, 0.0627-1	dresser1c.jpg	sofa2.jpg	Dresser	RGB: 0.4431-1, 0.1961-1, 0.1373-1
dresser2.jpg	2	Furniture	2	Non-Seating	RGB: 0.1647-1, 0.0667-1, 0.0196-1	dresser2c.jpg	chair2.jpg	Dresser	RGB: 0.4431-1, 0.3020-1, 0.0824-1
dresser3.jpg	2	Furniture	2	Non-Seating	RGB: 0.1412-1, 0.0118-1, 0.0078-1	dresser3c.jpg	deckchair2.jpg	Dresser	RGB: 0.1490-1, 0.0745-1, 0.0745-1
fan1.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0941-1, 0.0745-1, 0.2980-1	fan1c.jpg	wheelbarrow2.jpg	Fan	RGB: 0.1373-1, 0.1725-1, 0.1922-1
fan2.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0157-1, 0-1, 0-1	fan2c.jpg	axe2.jpg	Fan	RGB: 0.1216-1, 0.1216-1, 0.1176-1
fan3.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.3961-1, 0.4078-1, 0.4314-1	fan3c.jpg	hammer1.jpg	Fan	RGB: 0.6196-1, 0.6275-1, 0.6745-1
flashlight1.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0118-1, 0.0157-1, 0.0078-1	flashlight1c.jpg	hammer2.jpg	Flashlight	RGB: 0.1412-1, 0.1412-1, 0.1412-1
flashlight2.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.5843-1, 0.5490-1, 0.1373-1	flashlight2c.jpg	axe1.jpg	Flashlight	RGB: 0.7882-1, 0.7882-1, 0.4549-1
flashlight3.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0902-1, 0.1922-1, 0.1137-1	flashlight3c.jpg	wheelbarrow3.jpg	Flashlight	RGB: 0.0078-1, 0.0078-1, 0.0078-1
gloves1.jpg	4	Clothing Items	2	Accessories	RGB: 0.0275-1, 0.0118-1, 0.0431-1	gloves1c.jpg	pants1.jpg	Gloves	RGB: 0.1373-1, 0.1333-1, 0.1529-1
gloves2.jpg	4	Clothing Items	2	Accessories	RGB: 0.1020-1, 0.1137-1, 0.1255-1	gloves2c.jpg	long-sleevedshirt2.jpg	Gloves	RGB: 0.0824-1, 0.0824-1, 0.0824-1
gloves3.jpg	4	Clothing Items	2	Accessories	RGB: 0-1, 0.0510-1, 0.0118-1	gloves3c.jpg	shirt2.jpg	Gloves	RGB: 0.0549-1, 0.1176-1, 0.0784-1
hammer1.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0.3686-1, 0.3411-1, 0.2588-1	hammer1c.jpg	flashlight2.jpg	Hammer	RGB: 0.5490-1, 0.4784-1, 0.2980-1
hammer2.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0706-1, 0.0863-1, 0.0824-1	hammer2c.jpg	washer3.jpg	Hammer	RGB: 0.0039-1, 0.0039-1, 0.0039-1
hammer3.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.1569-1, 0.1373-1, 0.0941-1	hammer3c.jpg	fan2.jpg	Hammer	RGB: 0.0039-1, 0.0039-1, 0.0039-1
hat1.jpg	4	Clothing Items	2	Accessories	RGB: 0-1, 0.3059-1, 0.4902-1	hat1c.jpg	shirt3.jpg	Hat	RGB: 0.0824-1, 0.3843-1, 0.6431-1
hat2.jpg	4	Clothing Items	2	Accessories	RGB: 0.0902-1, 0-1, 0-1	hat2c.jpg	long-sleevedshirt3.jpg	Hat	RGB: 0.4902-1, 0.0588-1, 0.0588-1
hat3.jpg	4	Clothing Items	2	Accessories	RGB: 0.3725-1,	hat3c.jpg	pants3.jpg	Hat	RGB: 0.4392-1, 0.6392-1, 0.2431-1

					0.5137-1, 0.0863-1				
long-sleevedshirt1.jpg	4	Clothing Items	1	You wear	RGB: 0-1, 0.216-1, 0.2039-1	long-sleevedshirt1c.jpg	hat1.jpg	Long-sleeved shirt	RGB: 0-1, 0.3725-1, 0.6157-1
long-sleevedshirt2.jpg	4	Clothing Items	1	You wear	RGB: 0-1, 0.0706-1, 0.1686-1	long-sleevedshirt2c.jpg	bowtie3.jpg	Long-sleeved shirt	RGB: 0.1059-1, 0.1529-1, 0.2471-1
long-sleevedshirt3.jpg	4	Clothing Items	1	You wear	RGB: 0.6863-1, 0.4941-1, 0.2196-1	long-sleevedshirt3c.jpg	gloves1.jpg	Long-sleeved shirt	RGB: 0.3647-1, 0.2392-1, 0.0314-1
pan1.jpg	3	Cook and Tableware	1	Eating	RGB: 0.0627-1, 0.04701-1, 0.0392-1	pan1c.jpg	pitcher2.jpg	Pan	RGB: 0.0196-1, 0.0196-1, 0.0196-1
pan2.jpg	3	Cook and Tableware	1	Eating	RGB: 0.0627-1, 0.0588-1, 0.0549-1	pan2c.jpg	coffeemug2.jpg	Pan	RGB: 0.1176-1, 0.1176-1, 0.1176-1
pan3.jpg	3	Cook and Tableware	1	Eating	RGB: 0.2471-1, 0.1294-1, 0.1333-1	pan3c.jpg	wineglass3.jpg	Pan	RGB: 0.2706-1, 0.1059-1, 0.1098-1
pants1.jpg	4	Clothing Items	1	You wear	RGB: 0.1294-1, 0.1608-1, 0.2275-1	pants1c.jpg	hat3.jpg	Pants	RGB: 0.1804-1, 0.2431-1, 0.2824-1
pants2.jpg	4	Clothing Items	1	You wear	RGB: 0.3725-1, 0.3529-1, 0.3412-1	pants2c.jpg	gloves3.jpg	Pants	RGB: 0.4902-1, 0.4824-1, 0.4863-1
pants3.jpg	4	Clothing Items	1	You wear	RGB: 0.6863-1, 0.3137-1, 0.7490-1	pants3c.jpg	bowtie2.jpg	Pants	RGB: 0.7843-1, 0.3412-1, 0.8980-1
pitcher1.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.0314-1, 0.1765-1, 0.0588-1	pitcher1c.jpg	bowl3.jpg	Pitcher	RGB: 0.0235-1, 0.0980-1, 0.0471-1
pitcher2.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.0392-1, 0.0549-1, 0.0275-1	pitcher2c.jpg	spoon2.jpc	Pitcher	RGB: 0.0706-1, 0.0706-1, 0.0706-1
pitcher3.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.4706-1, 0.4667-1, 0.4706-1	pitcher3c.jpg	pan2.jpg	Pitcher	RGB: 0.3255-1, 0.3020-1, 0.3569-1
shirt1.jpg	4	Clothing Items	1	You wear	RGB: 0.4353-1, 0.0471-1, 0.0471-1	shirt1c.jpg	hat2.jpg	Shirt	RGB: 0.0784-1, 0.0235-1, 0.0235-1
shirt2.jpg	4	Clothing Items	1	You wear	RGB: 0.1608-1, 0-1, 0.2863-1	shirt2c.jpg	gloves2.jpg	Shirt	RGB: 0.1137-1, 0.0549-1, 0.1765-1
shirt3.jpg	4	Clothing Items	1	You wear	RGB: 0.5373-1, 0.0706-1, 0.0706-1	shirt3c.jpg	bowtie1.jpg	Shirt	RGB: 0.3961-1, 0.0784-1, 0.0745-1
sofa1.jpg	2	Furniture	1	Seating	RGB: 0.3882-1, 0.0078-1, 0.0510-1	sofa1c.jpg	dresser1.jpg	Sofa	RGB: 0.2314-1, 0.0588-1, 0.0588-1
sofa2.jpg	2	Furniture	1	Seating	RGB: 0.2863-1, 0.1961-1, 0.1569-1	sofa2c.jpg	desk2.jpg	Sofa	RGB: 0.3412-1, 0.1216-1, 0.0549-1
sofa3.jpg	2	Furniture	1	Seating	RGB: 0.4941-1, 0.1098-1, 0.0314-1	sofa3c.jpg	table3.jpg	Sofa	RGB: 0.6627-1, 0.3686-1, 0.2471-1

spoon1.jpg	3	Cook and Tableware	1	Eating	RGB: 0.1294-1, 0.1529-1, 0.1529-1	spoon1c.jpg	wineglass1.jpg	Spoon	RGB: 0.1412-1, 0.1412-1, 0.1412-1
spoon2.jpg	3	Cook and Tableware	1	Eating	RGB: 0.1216-1, 0.0863-1, 0.0471-1	spoon2c.jpg	pitcher1.jpg	Spoon	RGB: 0.3255-1, 0.2471-1, 0.1451-1
spoon3.jpg	3	Cook and Tableware	1	Eating	RGB: 0.0431-1, 0.0627-1, 0.0627-1	spoon3c.jpg	coffeemug3.jpg	Spoon	RGB: 0.0784-1, 0.0784-1, 0.0784-1
table1.jpg	2	Furniture	2	Non-Seating	RGB: 0.0980-1, 0.0471-1, 0.0078-1	table1c.jpg	sofa3.jpg	Table	RGB: 0.4353-1, 0.3882-1, 0.3412-1
table2.jpg	2	Furniture	2	Non-Seating	RGB: 0.0667-1, 0.0314-1, 0.0314-1	table2c.jpg	deckchair1.jpg	Table	RGB: 0.3059-1, 0.1752-1, 0.1752-1
table3.jpg	2	Furniture	2	Non-Seating	RGB: 0.0471-1, 0.0235-1, 0-1	table3c.jpg	chairoption1.jpg	Table	RGB: 0.0627-1, 0.0471-1, 0.0275-1
washer1.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.2706-1, 0-1, 0.0941-1	washer1c.jpg	axeoption1.jpg	Washing machine	RGB: 0.5059-1, 0.1490-1, 0.2039-1
washer2.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0980-1, 0-1, 0.1333-1	washer2c.jpg	wheelbarrow1.jpg	Washing machine	RGB: 0.1176-1, 0.1176-1, 0.0980-1
washer3.jpg	1	Tools/ Appliances	1	Electric	RGB: 0.0118-1, 0.0078-1, 0.0039-1	washer3c.jpg	hammer3.jpg	Washing machine	RGB: 0.0784-1, 0.0784-1, 0.0784-1
wheelbarrow1.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.1373-1, 0.0275-1, 0.0510-1	wheelbarrow1c.jpg	fan3.jpg	Wheelbarrow	RGB: 0.7608-1, 0.0588-1, 0.0588-1
wheelbarrow2.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0510-1, 0.1725-1, 0.1961-1	wheelbarrow2c.jpg	washer2.jpg	Wheelbarrow	RGB: 0.0824-1, 0.1216-1, 0.1333-1
wheelbarrow3.jpg	1	Tools/ Appliances	2	Non-electric	RGB: 0.0078-1, 0.0078-1, 0.0078-1	wheelbarrow3c.jpg	flashlight3.jpg	Wheelbarrow	RGB: 0.0392-1, 0-1, 0-1
wineglass1.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.1451-1, 0.1451-1, 0.1451-1	wineglass1c.jpg	spoon3.jpg	Wine glass	RGB: 0.2314-1, 0.2314-1, 0.2314-1
wineglass2.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.0235-1, 0-1, 0.2627-1	wineglass2c.jpg	bowl2.jpg	Wine glass	RGB: 0.0039-1, 0-1, 0.0863-1
wineglass3.jpg	3	Cook and Tableware	2	Drinking	RGB: 0.1412-1, 0.1020-1, 0.2353-1	wineglass3c.jpg	pan1.jpg	Wine glass	RGB: 0.1804-1, 0.1608-1, 0.3216-1

The stimuli edit work detailed in Appendix B and Appendix D described below was carried out by Andrea Eccher for her work in our group as a Master's student.

Appendix B: Edited Stimuli Details for Experiments 2, 3 and 4

In **Experiments 2, 3** and **4**, the same 72 base image stimuli files from **Experiment 1** were used. The difference was that these images all had been edited in Adobe Photoshop into the following four-color groups: 1) black (RGB: 0, 0, 0), 2) blue (RGB: 13, 69, 100), 3) brown (RGB: 104, 53, 2), and 4) green (RGB: 4, 77, 48). This resulted in 288 total stimuli (72 in each of the four-color groups). The same categories and sub-categories were also used as described in Appendix A and shown in **Table 1A**. After the above color groups were added to the items, tonal values were adjusted when needed, in situations in which either the original stimuli were too light or too dark.

Tonal value adjustments were altered within a range from "0.1" - "2". See **Figure 1B** for an example of two image exemplars (bowtie 1 and axe 1) in each of the four-color groups.

Appendix Figure 1B

Importantly, also corresponding with **Experiment 1**, the same image probe changes (for example “axe 2” changing from memory array to probe array to “flashlight 1”, **Figure 1A**) as in **Experiment 1** were used in this experiment as well.

The probe object had the same color and the same orientation as the original image it was replacing from the memory array. For example: **blue** axe 2 in the memory array would change to **blue** flashlight 1 in the test array.

The images used in Chapter 4 (Experiments 3 and 4) were the same as Experiment 2 of Chapter 3 described above.

Appendix B: Visual Saliency Analyses

Using the Saliency Toolbox in MATLAB (Walther & Koch, 2006; github.com/DirkBWalther/SaliencyToolbox), a post hoc analysis was conducted examining the possible differences between color salience of probe items and the accompanying images presented in the display.

Analyses were separated high similarity conditions from low similarity conditions. For both analyses, color saliency means were calculated for probe items and for "distractor objects", or the objects that were also presented in the display along with the probe. Then a paired samples t-test was conducted comparing the means of these probe and distractor color saliency values.

Color Saliency Paired Samples t-test results for High Similarity conditions

A paired samples t-test for high similarity conditions indicated that color saliency values were not significantly different from probe objects (M=23.183, SD=0.879) to distractor objects (M=30.147, SD=22.874; $t(29) = -1.667$, $p = 0.106$, $d = -0.304$).

Color Saliency Paired Samples t-test results for Low Similarity conditions

A paired samples t-test for low similarity conditions indicated that color saliency values were not significantly different from probe objects (M=22.764, SD=0.897) to distractor objects (M=29.295, SD=19.686; $t(29) = -1.817$, $p = 0.080$, $d = -0.332$).

Appendix C: Experiment 3 Reaction Time, Accuracy and Search Slope Results

Reaction Times

The repeated measures ANOVA on mean reaction times (RT) for correct responses found an effect of similarity condition, $F(1.449, 166.484) = 138.002$, $p < .001$, $\eta p2 = 0.730$, $BF_{10} = 2.549e + 22$. Post hoc comparisons with FDR correction demonstrated each of the similarity conditions to be significantly different (p = 0.0010).

The interaction between similarity condition and age group was not significant, $F(1.449, 166.484) = 0.731$, $p = 0.443$, $\eta p2 = 0.014$, $BF_{10} = 2.724e + 26$ nor was the three-way interaction between similarity condition, set size and age group, $F(3.214,166.484) = 0.153$, $p = 0.937$, $\eta p2 = 0.003$, $BF_{10} = 4.188 e + 101$, nor was similarity, set size, target presence and age group, $F(3.264, 166.484) = 0.173$, $p = 0.927$, $\eta p2 = 0.003$, $BF_{10} = 6.004e + 218$.

There was a significant interaction between set size and age group, $F(1.194, 166.484) = 10.852$, $p < .001$, $\eta p2 = 0. 175$, $BF_{10} = 1.812e + 68$. Post hoc comparisons with FDR correction found all three of the set sizes to be significantly different between the two age groups (p<.001). There was also a significant interaction between set size, target presence and age group, $F(1.686, 166.484) = 10.564$, $p < .001$, $\eta p2 = 0.172$, $BF_{10} = 7.294e + 159$. Post hoc comparisons with FDR correction found all three of the set size conditions when the target was both present and absent to be significantly different between the two age groups (p<.001). There was an overall between subjects age effect, $F(1, 51) = 30.068$, $p <.001$, $\eta p2 = 0.371$, BF10 = 10875.140. The interaction between age group and target presence was also significant, $F(1, 204) = 22.855$, $p = <.001$, $\eta p2 = 0.309$, $BF_{10} = 7.714e + 63$. Post hoc comparisons with FDR correction indicated that YA and OAs were significantly different from each other in both target present conditions (p<.001) and in target absent conditions (p<.001).

The three-way interaction between similarity condition, target presence and age group was not significant, $F(1.686, 166.484) = 0.520$, $p = 0.566$, $\eta p2 = 0.010$, $BF_{10} = 1.440e+96$.

Accuracy

A repeated measures ANOVA on error rates demonstrated a significant effect of similarity condition, $F(2, 204) = 15.037$, $p < .001$, ηp2 = 0.228, $BF_{10} = 13.545$. Post hoc analyses with FDR correction found significantly higher error rates for both age groups in the perceptual similarity condition in comparison to the other two conditions (p<.001). The amount of errors in the conceptual and baseline conditions were not significantly different from each other however (p=0.8833).

There were no significant interactions between age group and similarity condition in error rates, $F(2, 204) = 2.635$, $p = .077$, ηp2 = 0.049, $BF_{10} = 5585.929$, or age group and set size, $F(2, 204) = .762$, $p = .470$, ηp2 = 0.015, $BF_{10} = 1562.707$, or similarity condition, set size and age group, or set size, target presence and age group, $F(4, 204) = .797$, $p = 0.528$, ηp2 = 0.015, $BF_{10} = 22195.277$ and $F(1.764, 190.720) = 1.147$, $p = 0.317$, ηp2 = 0.022, $BF_{10} = 6.415e+62$, respectively.

There was a significant interaction between age group and target presence, $F(1, 204) = 7.259$, $p = .010$, ηp2 <.001, $BF_{10} = 2.318e+61$. Post hoc analyses with FDR correction found significantly different error rates between the two age groups in the target present conditions and the target absent conditions (both p <.001).

There was no significant interaction between age group, set size, target presence and similarity condition, $F(4.000, 204.000) = 1.868$, $p = .122$, ηp2 = 0.035, $BF_{10} = 1.769e+65$.There was an overall age effect in error rates, $F(1, 51) = 20.242$, $p < .001$, ηp2 = 0.284, $BF_{10} = 423.488$.

Search Slopes

A repeated measures ANOVA on slope values demonstrated a significant effect of similarity condition, $F(1.576) = 45.674$, $p < .001$, ηp2 = 0.472, $BF_{10} = 3.283e+8$. Post hoc analyses with FDR correction found significantly higher slope values for both age groups in all three of the similarity conditions, both when the target was present and absent (p < .02).

There was no significant interaction between age group and similarity condition in slope values, *F* (1.576, 86.718)) = 0.132, *p* = .828, ηp2 = 0.003, BF_{10} = 8.241e+9. There was a significant interaction between target presence and age group in slope values, *F* (1, 86.718)) = 15.924, *p* = < .001, ηp2 = 0.238, BF_{10} = 3.548e+28. Post hoc analyses with FDR correction found significant differences between the two age groups in slope values both when the target was present (p = .0321) and absent (p< .001).

There was no significant interaction between similarity condition, age group and target presence, *F*(1.700, 86.718) = 0.061, *p* = .917, ηp2 = .001, BF_{10} = 4.036e+44. There was an overall age effect in slope values, *F*(1, 51) = 11.984, *p* < .001, ηp2 = 0.190, BF_{10} = 23.653.

Appendix D: Chapter 5 Age-related Oculomotor Effects in Real-World Object Search Stimuli Details

In **Experiment 5**, the 72 original base images from the previous four experiments were amended. 10 new image item types were added to this set (cookpots, grills, helmets, knives, lawnmowers, plates, stools, stoves, suits and wooden boxes) also derived from the "Object categories" repository (Konkle et al., 2010). Additionally, the item types of flashlights and wineglasses from the previous experiments were removed from the original base images for this experiment in order to have an even amount of image items in each of the four categories.

The 24 item types were subdivided into the four main object categories: 1) Tools / Appliances, 2) Furniture, 3) Cook / Tableware and 4) Clothing. Each of the four categories had 8 total image exemplars (fans, grills, etc.). Of the 24 total image item types, there were 3 exemplars per item type (for example there were three different fans: fan 1, fan 2 and fan 3). Sub-category as was used in the previous experiments was disregarded in **Experiment 5**, as it was not relevant for the overall aim of Experiment 5. A full list of stimuli used and their corresponding category is available upon request.

For this experiment, the original images from the Aude Oliva repository (Konkle et al., 2010) used in the previous experiments that had been re-oriented or had the base color edited in Experiment 1, were redownloaded and then edited with the following criteria, in order to have images presented at their original orientation as well as the color edits added with the original background colors, as opposed to being presented with the orientation changes described in Appendix A.

Each of the 96 images were edited into each the four-color groups: 1) black (RGB: 0, 0, 0), 2) blue (RGB: 13, 69, 100), 3) brown (RGB: 104, 53, 2), and 4) green (RGB: 4, 77, 48). After the color group edits were made, tonal values were also adjusted when needed within a range: "0.1" to "1".

Mid-level color changes

The next important stimuli edit were the mid-level color changes. For these mid-level color changes, tonal values were adjusted to a value of “2” for all images. Then, if the image color was not salient, afterwards, the luminosity was changed. For stimuli that needed to be lightened, a luminosity of +50 was added, and for stimuli that needed to be darkened, a luminosity of -60 was added (with a select few that were very dark or very light originally). For example, one image (stove 2) that was originally very dark, so a luminosity of +120 was added. For an example, the axe 2 and flashlight 3 in **Figure 1C** had a luminosity change of -60, while the washing machine 1 and dresser 2 images in **Figure 2C** had a luminosity change of +50. A full list of images with these luminosity changes and their corresponding values is available upon request.

Appendix Figure 1D

Luminosity Color Example Darkened Stimuli in Experiment 5

Axe 2

Flashlight 3

Appendix Figure 2D

Luminosity Color Example Lightened Stimuli in Experiment 5

Washing Machine 1

Dresser 2

An example of five images for each of the eight color group changes is provided below (**Figure 3D**).

Appendix Figure 3D

Eight Color Group Examples for Experiment 5 Stimuli

Appendix D: Chapter 5 Age-related Oculomotor Effects in Real-World Object Search

Reaction Time Criteria

The following inclusionary criteria was applied to reaction time analyses (5.2.5.1):

1) Only accurate responses.

2) Reaction times that were less than 800 milliseconds from the time the stimuli were presented on the screen and the participant left the fixation.

3) Reaction times that were less 1.4 seconds from the time that the stimuli were presented and the subject looked at the target.

4) Reaction times less than 800 milliseconds in which the participant was outside the fixation area and arrived at the target.

5) Calculations were then made on the amount of points of the gaze position in the participants' trajectories. These points were read by the eye tracker in real time and calculated through MATLAB and were indication of the participant's eye movement trajectory.

   a. First, only trajectories in which the eye movements towards the target were less than 600 points. More points than 600 were taken to be either too long of movement trajectories, or movements not recorded well (possibly due to bad calibration).

   b. Next, only trajectories of less than 15 points towards and on the distractor side of the screen were included.

   c. The next calculation that was done based on trajectory recordings was to disregard trajectories which were too indirect, possibly either due to the subject or due to bad calibration.

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