Categorical bias in VWM in healthy aging:

Does VWM become more categorical as we get older?

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Abstract

Visual working memory (VWM) is defined as the limited amount of visual information that can be maintained when visual stimuli are not visible. This information can either be stored as a categorical (e.g., red) or as a continuous representation (e.g., a hue of red). Studies have shown that people tend to respond based on the general category that an item belongs to, especially when they need to store many items in their VWM. This we define as categorical bias. Many studies have shown that during healthy aging, VWM capacity is reduced and the precision of representations in VWM declines. The aim of this study is to compare VWM representations in healthy, older adults with those in middle-aged and younger adults, to determine whether older adults show a stronger categorical bias than young adults do, and to what extent the categorical bias of older adults depends on the number of items that they need to remember. In order to complete this project, we collected data in an online task from 90 people in evenly distributed age groups, 18-29, 30-59, 60-70. On each trial, a memory display with colored circles was placed evenly in a circular arrangement around a fixation dot. The size of the set was between 1 and 4 memory items. We used a color delayed estimation task, and we analyzed the responses with a mixture model with three parameters, each of the parameters was fitted to the Response Bias (the error in the direction of category prototypes) which allowed us the access to categorical representations of VWM in healthy, older people. We found that VWM representations become progressively more categorical with increasing set sizes as well as with increasing age.

Keywords: aging, categorical bias, representations, Visual Working Memory

Introduction

Visual working memory (VWM) is a system that stores relevant visual information, which provides an interface between perception, long term memory and action (Baddeley et. al, 2013). A traditional theory is that this VWM information can be stored as continuous representations, which are referred to as specific details of the visual characteristics of the object (e.g., “a light shade of green”) (Bays et al, 2009; Bays et al., 2011).

However, recent studies have shown that VWM can also be stored as categorical representations, which are referred to as a general category that an object belongs to, (e.g., “something green”) (Hardman et al, 2017; Bae & Luck, 2019). Hardman and colleagues (2017) tested participants in a color delayed estimation task by asking them to remember one, three, or five color hues; after a delay period, they indicated the memorized colors on a color circle. In order to assess whether information is stored categorically the authors tested whether participants’ responses were closer to the prototypical color category location. The authors found that VWM representations became more categorical when storing more than one item. This result is consistent with a study by Bae & Luck in 2019, who tested 16 young college students and required them to remember the orientation of a sample teardrop and reproduce it, while performing a visual discrimination task. Their results showed that when VWM consumed more resources, participants' memory was more categorical as they responded in cardinal orientations and were less accurate.

Taking the above into account we can assume that continuous representations consume more VWM resources; therefore, the capacity limit for continuous representations is stronger than the limit for categorical representations. Because of this stronger capacity limit for continuous representations, in increased memory load conditions, representations would tend to become more categorical.

A discussion that is related to the distinction between categorical and continuous representations is the debate between discrete slot models (Zhang & Luck, 2008; Zhang & Luck, 2011) and resource models of VWM (Bays et al, 2008). For example, Bays and Hussain (2008) tested participants on their precision on the location and orientation of a previously shown colored square. They showed that even in small set sizes, precision declined as set sizes increased. They interpreted this finding as evidence for a fixed pool of resources, which is distributed across all items that are maintained in VWM, such that precision declines with increasing set size because fewer resources are allocated to each item. The concept of resources is related to continuous representations because a continuous representation can become more or less precise, whereas a categorical representation is all-or-none, which is more related to slot models.

In contrast to the notion of resources, Zhang & Luck in 2008, based on the results of a color recall task, argued that memory representations are stored in discrete slots, where each slot stores a representation of a stimuli and what is perceived in the end is the average of these representations. They tested 8 participants in a color recall task with set sizes 3 and 6. They found that precision of recalling the set items was not influenced by the set size, since it was almost the same for both. However, they found that the probability of the cued item being present in memory was higher for the small set size compared to the larger set size. Their interpretation was that stimuli are stored in district slots in VWM and what is reported, is the average of these representations. This would explain the same precision that was observed in their experiment, despite the higher probability that the cued item was absent from memory in the 6-set size.

Besides memory load, VWM capacity is also influenced by aging. In a study by Brockmole and Logie (2013), a large number of participants from younger to older age were tested on a memory task where they memorized various number of items (one to four), after which they recalled the color, the shape and the location of these items. Their results showed that older people aged 75 years old had two-thirds drop in their memory capacity compared to younger people aged 20 years old. Generally, it was observed that following a linear decline of VWM after 20 years old, adults aged around 60 years old and older had the most deteriorated VWM, even lower from the youngest age group of the study which included 8-year-old children. However, an important question that still remains unanswered is whether older adults rely more on categorical representations due to declined capacity as they age.

To summarize the findings above: with increased memory load, the precision with which visual features are recalled declines. Furthermore, the precision of VWM declines with age (Tas et al. 2020; Peich et al., 2013). However, in aging research little attention has been paid to the nature of representations in VWM and whether they become more categorical with increased age. Recently, however, evidence for an aging effect on the nature of VWM representations was shown. In a recent study (Pilz et al, 2020) young and older participants were tested on an orientation discrimination task.

They were asked to identify whether two Gabors that were shown had the same or a different orientation. In orientation tasks, the main categories are “vertical” and “horizontal”, and thus the prototypes that define a category are at the cardinal axes. Interestingly, the authors showed that for the oblique (continuous) representations older participants performed worse, whereas for cardinal (categorical) representations there was no difference between the age groups. In other words, this is evidence of an ageing effect, such as that older people are worse than younger people at a VWM task when they cannot rely on categories (oblique orientations in this case), but that their performance is preserved when they can rely on categories (cardinal orientations in this case). This finding could be attributed to the increased experiences they have with categories, which can be translated into categorical bias.

Based on the above, the aim of the current study is to compare VWM representations in healthy, older adults with middle-aged and younger adults, to determine whether older adults show a stronger categorical bias than middle and young adults do, and to what extent the categorical bias of older adults depends on the number of items that they need to remember. In order to do that we will use a color delayed estimation task which is one of the most common tasks to measure VWM capacity, and the nature of representations in VWM. Participants need to memorize a set of colors that are varied on a continuum. After a delay, the exact colors need to be reproduced. This task can measure whether older people report the memorized color based on its exact hue (a continuous representation), or rather whether they (mis)report the memorized color as the prototypical color of the associated color category (a categorical representation).

Our main prediction is that visual working memory (VWM) becomes more categorical as age increases. Specifically, we predict that in younger adults, VWM largely relies on continuous representations; however, because VWM capacity for continuous representations declines with age, VWM relies more on categorical representations as age increases. Moreover, we predict that VWM becomes progressively more categorical with increased memory load. Specifically, we predict that when memory load is low, VWM mainly relies on continuous representations; however, because of the limited storage capacity of continuous representations in VWM, VWM relies more on categorical representations as memory load increases.

Method

The present study was carried out online, through Prolific platform (www.prolific.co). After completing the experiment, participants received €7 per hour. In total, 90 people participated in our study. They were divided into three age groups; a young age group, a middle age group and an old group, with ages (18-29), (30-59), (60- 70) respectively. Because we wanted to opt for equal numbers of participants in each group, 30 participants comprised each of the groups. They reported no optical or cognitive decline. We received approval of the Ethics Committee of Psychology of the University of Groningen (PSY-2021-S-0357).

In order to measure the categorical bias, we utilized a color delayed estimation task. The experimental procedure was created with OpenSesame ((version 3.3; Mathôt et al., 2012) and it began by showing colored circles of color values in a memory display, which were placed evenly around a fixation mark for 500ms. The number of the circles that were shown in each trial could be either 1,2, 3 or 4, as we wanted to test our results in different set sizes. Colors were sampled from hue-saturation-value (HSV) color space with full saturation and value. Luminance ranged from 49 cd/m² to 90 cd/m² on a typical lab monitor. The experiment was conducted through each individual's computer monitor; therefore, the luminance of the colors the participants viewed varied depending on that. After that, a 2000ms delay followed and then an arrow appeared for 300ms which pointed towards the location of a color that was previously shown. Participants reproduced the color by clicking on a color wheel, which was randomly rotated on each trial. There was no timeout for their response. After they had chosen the color, feedback followed for 500ms, showing the cued and the reported color. In total 800 trials were completed for each participant. There were 4 sessions, comprised of 8 blocks and each block included 25 trials, hence 800 trials.

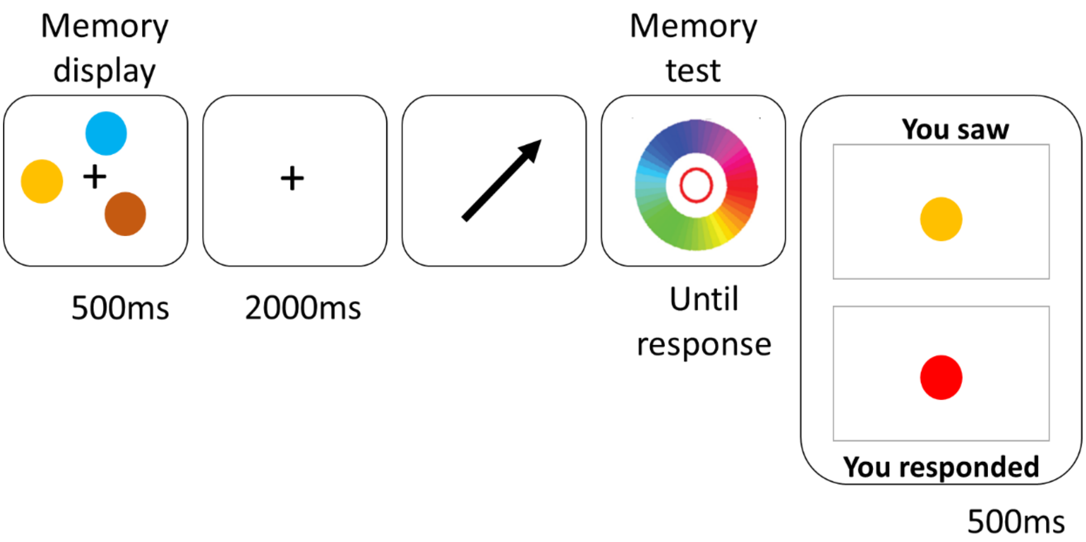

Figure 1. Sequence of events of a trial with a Memory Load of three.

Analysis

To analyze our results, we first fitted our data in a Mixture model and as a second step conducted repeated measures analyses of variance (RM- ANOVA). The Mixture model we used in the present study was a model that was represented by two distributions, namely a von Mises and a uniform distribution. Our model had three parameters, the Guess Rate, the Precision and the Bias. Each of these parameters can be expressed by the terms of the distribution as follows. The Guess Rate refers to the baseline of the distribution, the higher the baseline, the higher the proportion of random responses. If the value for Guess Rate was 0, this would correspond to a pure von Mises distribution, since the baseline would be on the x axis, without any random responses. The second parameter was the Precision, which was expressed it terms of the width of the distribution: the wider it was, the lower the Precision, the narrower it was, the higher. The third parameter of our model was the Bias, which corresponded to the mean of the distribution. If the Bias was positive, this meant that participants responded in the direction of the prototypical colors, therefore a right shift in the distribution, while if the Bias was negative this meant they responded in the direction away of the prototypical colors, therefore a left shift in the distribution. We fitted the model's parameters for every combination of participant and condition separately, namely for 90 participants and for every set size (1,2,3,4). We fitted these three parameters to the Response Bias, which referred to the angular error between the two values, the value that was reported and the cued values. It should also be mentioned that the positive and negative values of the Response Bias did not depend on clockwise or anticlockwise orientation of the error, but they referred to whether participants responded towards the prototypical category of the color that was cued in each trial. Basing the analysis of our results on the Response Bias, facilitated our understanding whether people responded with categorical Bias. The model is available through https://github.com/smathot/biased_memory_toolbox/

The second step of our analysis included three separate repeated measures analyses of variance (RM-ANOVA). The depended variables for each analysis were the three parameters, namely Guess Rate, Precision and Bias. There were two independent variables, age and set size; however, age was a between- subject factor while set size was a within- subject factor. Our first prediction was that Guess Rate would increase with increasing age and increasing set size. We also predicted that Precision would decrease with increasing age and increasing set size. In line with previous studies, we predicted that visual working memory (VWM) would become more categorical as age increased (18-29 < 30- 59 < 60- 70). Specifically, we predicted that Bias would increase with age. Our second main prediction was that visual working memory (VWM) would become more categorical as set size increased. Specifically, we predicted that Bias would increase with memory set items (1 < 2 < 3< 4). We did not have specific predictions about a possible interaction between set size and age.

We conducted a RM – ANOVA with Guess Rate as the dependent variable and set size and age as the independent variables, as a within- subjects factor and a between- subjects factor respectively. We observed a very strong effect of set size on Guess Rate *($F(3, 264)= 60.073, p < .001$)*, such that Guess Rate increased with set size (see Figure 2). This finding is in accordance with our prediction. A second finding from these results is the interaction between set size and age *($F(6, 264)= 4.529, p < .001$)* on the Guess Rate, such that Guess Rate increased with increasing set size and increasing age. The effect of age on Guess Rate was non-significant *($F(2, 88) = 2.074, p > .05$)*, different to our prediction.

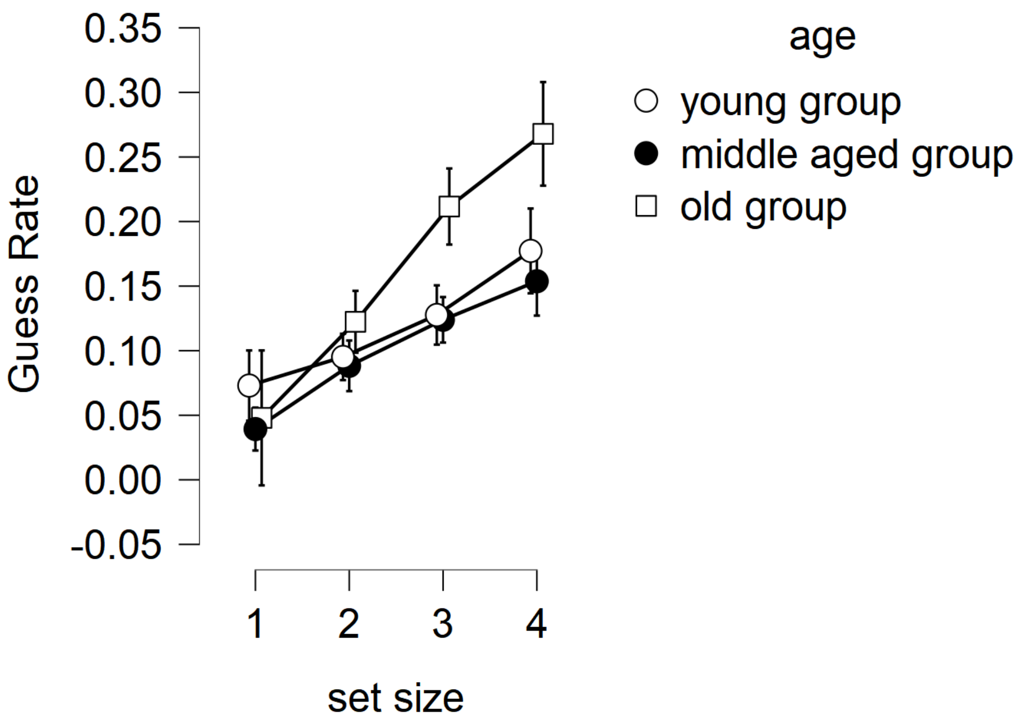

Figure 2. Descriptive plot of the effect of age and set size on guess rate.

We carried out a second RM- ANOVA with Precision as the dependent variable and set size and age as the independent variables, as a within- subjects factor and a between- subjects factor respectively. We observed a very strong effect of set size on Precision *(F (3, 264) =10.123, p < .001*), such that Precision decreased with set size (see Figure 3), which is congruent with our prediction. In addition to that, the effect of the interaction between set size and age on precision was non-significant (*F (6, 264)= 1.066, p > .05*). Interestingly, we did not find an effect of age on precision (*F (2, 88) = 1.002, p > .05*), which is different to our prediction. We also observed a nonlinear pattern in our descriptive plots. There is an almost linear pattern up to the 3-set size condition whereas for all age groups it seems that precision (and also the variance) increases for the 4- set size condition.

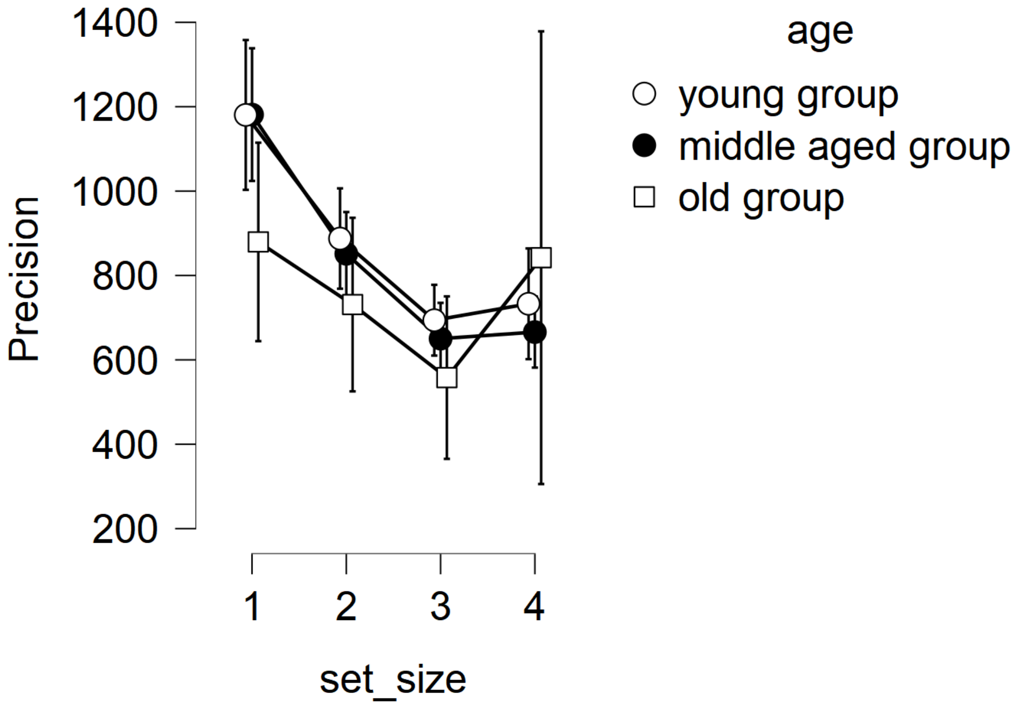

Figure 3. Descriptive plot of the effect of age and set size on precision.

In our third RM- ANOVA we used Bias as the dependent variable and set size and age as the independent variables, as a within- subjects factor and a between-subjects factor respectively. We found very strong evidence for the effect of set size on Bias ($F(3, 264) = 6.233, p < .001$), such that Bias increased with increasing set size (see Figure 4), which supports our prediction. There was not a significant effect in the interaction between age and set size on Bias ($F(6, 264)= 0.705, p > .05$) which is in agreement with our initial predictions. Moreover, there is an effect of age ($F(2, 88)= 3.321, p < .05$) on Bias, such that Bias increases with age. However, in our results whereas we found that Bias increases with set size for set size items 1 to 3, it is evident that for the 4-set size condition there is a decrease in all the age groups.

Figure 4. Descriptive plot of the effect of age and set size on Bias.

Conclusions

Here we tested whether the representations stored in visual working memory (VWM) become more categorical as people age. To test this, we collected data from 90 people divided into three equal age groups (18-29, 30, 59, 60- 70). The design of our study was slightly different than most studies in the way that we included a middle age group, whereas usually in aging research most researchers separate their participants into two age groups, one young and one older. In our research we divided our participants in a young group, a middle group and an older group. We conducted a color delayed estimation task with varying memory set items (1-4). To analyze our results, we utilized a mixture model of three parameters, Guess Rate, Precision and Bias which we fitted for every combination of participants and set items and fitted our data to the Response Bias. Following that, we carried out three RM- ANOVA analyses to test the statistical significance of our results.

We found that older people (60-70 years old) tend to respond with higher categorical bias compared to middle aged (30-59 years old) and younger people (18-29 years old). We also found that increasing the set size can lead to an increase in the categorical bias as well. In our research there is one breakthrough compared to previous studies. That is, to our knowledge no previous work has investigated how categorical representations in VWM change with increasing age. We showed that, as people age, VWM representations change: from continuous they become more categorical.

Previous research has focused on the representations that older people hold in their VWM; it has been shown that older people remember items with less precision (Peich et al, 2013; Ko et al, 2014). In the present study we showed that older people tend to form categorical representations more compared to younger age groups, even in low-capacity conditions, in order to remember colors in their VWM. That is, they remember the categories of colors more than the specific hues of colors. This is an important finding as it can help understand the reasons behind the decline in VWM capacity. To elaborate further on that, WVM requires more resources to form continuous representations compared to the resources required to form categorical representations. The maximum capacity of VWM is also reduced for older people, due to increased age. The reduced maximum capacity of older people's VWM limits even further the capacity to form continuous representations, which require increasing resources, especially for many set items. Therefore, older people tend to form instead categorical representations of the visual stimuli, which require less resources, in order to store the set items in their VWM. This explains why older people form categorical representations even in small set sizes compared to younger and middle-aged people. In other words, the representations become progressively more categorical with increasing age. This transition is important as it shows that in VWM the nature of representations is not constant but can change as a function of age. Our results are in agreement with previous research on orientation perception, which has indicated that older people have difficulty in maintaining continuous representations and form categorical representations (Pilz et al, 2020).

We also found that as set size increases categorical bias increases as well. The representations become progressively more categorical in high- capacity conditions. Storing more set items in VWM, the maximum capacity is reached. Continuous representations consume more resources to be formed so the capacity limit for them is stronger, therefore categorical representations are formed which require less resources. This result is in line with previous findings, where it was shown that with increased memory load, the extent to which representations are categorical increases as well (Hardman et al, 2017; Bae & Luck, 2019).

Furthermore, we examined the effect of set size on Guess Rate and found that as set size increases Guess Rate increases as well, the more items people need to store in their VWM, the higher the chance that many of their responses will be the result of guessing. We also found that with the interaction between age and set size the guess rate increases as well. While Guess Rate increases with set size for all age groups, it does so especially strongly for the older age group. Older people have declined maximum VWM capacity compared to younger and middle-aged people, hence, requiring them to maintain larger set sizes in their VWM, the sooner their VWM maximum capacity is reached. As a result, their responses tend to be produced by guessing.

Another prediction we made was that Precision increases with increased set size, and this was supported by our results. With increased set size, therefore reaching the maximum capacity of VWM, participants were less precise in their responses.

Interestingly, we showed that in set size 4 condition, our results were unexpected in two of our three parameters, Bias and Precision. We showed that in set size 4, there is a decrease in categorical bias, which could be attributed to the limitations of our study. One explanation would be that in the 4- set size condition, the same color appeared more than once, hence not all the colors were different. In other words, instead of remembering 4 different colors, only one or two were different and the rest were the same, which could lead to a reduce in the categorical bias since people responded more accurately on the cued color. There is also the possibility that Bias decreased because Guess Rate was very high, hence our model parameters became unreliable. We also noted that in the 4-set item condition, Precision increased for all age groups. One possible explanation to interpret that would be that the Guess Rate became so high, so it became difficult for the model to estimate the Precision, because there was so much random guessing.

To summarize the main findings from this research, it is shown that as people age, they have more categorical representations in their VWM, the fact that elderly people rely more on categorical representations allows them to have relatively intact VWM performance, despite having reducing capacity. Basically, categorization can be thought as a compensation mechanism. We also found that as set size increases, categorical bias increases leading to less precision and higher guessing rate. However, taking all of the above into account, there is still a question that remains unanswered, as to why do older people have higher categorical bias compared to middle aged and younger aged people. One possible explanation for that would be because they have a lifetime of experience with categories that younger people do not have. The way that we perceive the world is a mixture of our sensory inputs and our experiences. Therefore, older people might weight more their prior experiences compared to the sensory input which could be translated into a higher categorical bias.

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