The effect of age on visual working memory

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Abstract

The inhibitory-deficit hypothesis suggests that recall abilities decline throughout the ageing process due to a decline in the suppression of irrelevant information. Thus, elderly people performed worse in visual working memory (VWM) tasks compared to young adults. It would be interesting to know whether the decline in recall preciseness can also be found in middle-aged people. Two opposing models have been introduced to explain VWM function, namely the limited capacity (LR) model and the discrete capacity (DC) model. Researchers tend to favor the LR model, which suggests that a certain amount of resources is available to encode specific features of an object. Since the implication of age is unclear, the present study aimed to bring new insight if age affects VWM function for middle-aged people and young adults. The precision of recall ability for both groups was tested with a delayed-estimated task. Prior, a task that controlled for individual difference in perception of color and orientation was implemented. Consequently, results cannot be ascribed to changes in perception. Results revealed that the interaction of age and attention condition affects VWM function. Further analysis showed that age affects the focus attention condition. Middle-aged people performed worse within the focus attention condition. However, more research is needed to replicate the influence of age. Overall, results were best explained by the LR model.

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1. Introduction

The deterioration of working memory due to ageing is a well-established fact (Chen, Hale, & Myerson, 2003; Jost, Bryck, Vogel, & Mayr, 2011; Myerson, Emery, White, & Hale, 2003; Vogel, McCollough, & Machizawa, 2005). Thereby, the inhibitory-deficit hypothesis suggests that elderly people are less able to suppress irrelevant information. Support for this hypothesis comes from Gazzaley, Clapp, Kelley, McEvoy, Knight, and D'Esposito (2008) who detected a deficit in filtering abilities for visual information in the elderly. Visual information is temporarily maintained by the visual working memory (VWM), a subsystem of working memory (Baddeley & Hitch, 1974; Markov, Tiurina, & Utochkin, 2019). Like working memory, VWM is also limited in terms of how much information can be held at a given time (Alvarez & Cavanagh, 2004; Cowan, 2001). The limited capacity of VWM is a highly debated topic with two opposing models, namely the “discrete capacity model” (DC) and the “limited resource model” (LR), while recent studies favor the latter (Ma, Husain, & Bays, 2014; Schneegans & Bays, 2019; Van den Berg, Zou, & Ma, 2019; Van der Lubbe, Borsci, & Miežytė, 2019; Wang, Cao, Theeuwes, Olivers, & Wang, 2017). Additionally, research indicated that the limited capacity of VWM further decreases throughout the adult lifespan (Crook & West, 1990). Yet such findings were only found in elderly people (Gazzaley et al., 2008; Jost et al., 2011; Van der Lubbe & Verleger, 2002). Thus, it would be interesting to know whether the decline can be detected earlier in an adult’s life, for example within the middle ages (40 to 60). Therefore, the present study aims to bring new insights if age affects the function of the VWM for middle-aged participants and young adults, and if so, to what degree.

The inhibitory-deficit hypothesis suggests that age affects VWM function due to a decline in response tendencies and the suppression of irrelevant features in elderly people (Hasher & Zacks, 1988). Thus, elderly people performed worse in a working memory task in contrast to young adults because they are less well able to focus their attention on relevant information. Support for this idea came from electroencephalography studies which detected a delay within the attention orientation phase for the elderly (Gazzaley et al., 2008; Jost et al., 2011; Van der Lubbe & Verleger, 2002). This finding indicated that the elderly needed longer to focus their attention. Furthermore, researchers detected a decline in prefrontal cortex abilities which seems to be essential for suppressing irrelevant information (McNab & Klingberg, 2008).

Up until now, most research focused on the decline in recall abilities in elderly people (Gazzaley et al., 2008; Hasher & Zacks, 1988; Jost et al., 2011; Van der Lubbe & Verleger, 2002). Similarly a study by Crook and West (1990), who tested the recall preciseness of participants between the ages of 18 to 90, showed that the largest decline in recall preciseness was to be found within the elderly participants. However, they were also able to find a small but significant difference in recall preciseness between middle-aged participants and young adults. Therefore, it would be interesting to know if the present study is able to find the difference in performance between the young adults (18 to 25) and the middle-aged participants (40 to 60) as well. Based on the idea that VWM capacity declines with age, two consequences follow: First, middle-aged participants score lower in a VWM test compared to young adults since they are less able to suppress irrelevant features; and second, middle-aged participants show a greater deficit within the focus attention condition compared to the divided attention condition because their filtering abilities are more required within the focus attention condition.

Two models have been proposed concerning the function of the VWM, namely the "limited resource model" (LR) and the "discrete capacity model" (DC). The latter emphasizes the object-based limited perspective, which suggests that VWM consists of several but limited "slots" in which information is stored (Cowan, 2001; Luck & Vogel 1997). However, recent research favors the LR model, which is based on the idea that humans have a limited capacity available to encode several features of objects (Fougnie & Alvarez, 2011; Ma et al., 2014; Schneegans & Bays, 2019; Van den Berg et al., 2019; Van der Lubbe et al., 2019; Wang et al., 2017; Wheeler & Treisman, 2002). Furthermore, the LR model presumes that the recall preciseness gradually declines when the capacity limit is reached (Ma et al., 2014; Markov et al., 2019). Like the inhibitory-deficit hypothesis, the LR model assumes that attention conditions have an impact on recall abilities, since one has the flexibility to decide on what to focus on (Van den Berg et al., 2019). Overall, the LR model supports the theory of a multi-storage system, which provides segregate capacities for different features (Delvenne & Bruyer, 2004; Markov et al., 2019; Wang et al., 2017).

A frequently used task to investigate VWM is the delayed-estimated task which facilitated the possibility to gain information about the quality of the memory. During the task, participants were asked to affirm a certain feature from an object which was shown beforehand (Ma et al., 2014). Van der Lubbe and colleagues (2019) indicated the necessity of implementing a pre-experimental period since participants' abilities to distinguish between different features differ largely from one another. More support for the implementation comes from a study by Tulver (2019) who concluded that humans each perceive their environment differently. Accordingly, the present study used a delayed-estimated task with the implementation of a pre-experimental period to control for individual difference in sensitivity perception for both features (color and orientation). Therefore, a difference in results cannot be traced back to difference in perception.

The goal of the present study is to explore if and how age affects the function of the VWM for middle-aged participants and young adults. The inhibition-decline hypothesis predicts an influence of age on the recall preciseness, especially in the focus attention condition. Consequently, middle-aged participants should score lower in the VWM task compared to young adults especially in the focus attention condition.

2. Method

2.1. Participants

Eighteen participants voluntarily took part in the experiment by signing the informed consent form. A convenience sampling method was used, implying that the sample was not random, in order to create two groups according to age. The first group, the “young adult group” consisted of 11 right-handed participants from various countries with a mean age of 20.18 (SD = 1.6, range = 18 – 24; German: 6; Irish: 2; Syrian: 1; half German and half Greek: 2). Seven participants of the young adult group are female (male = 4). Furthermore, five of them are studying at a university, three of them are still completing high school and the remaining three have not followed a university pathway. Lastly, six participants wear glasses normally. The remaining participants also come from various countries and were assigned to the second group, the “middle-aged group” (M_{age} = 56, SD_{age} = 2.08, $\text{range}_{\text{age}}$ = 54 – 60; German: 4, Irish: 2; Greek: 1). Four middle-aged participants are female (male = 3). Additionally, all of them are right-handed and wear glasses (one of them wears glasses for distance only and therefore did not wear glasses during the experiment). Only two participants studied at a university while the others did not.

All 18 participants, on asking, reported to have normal vision. A color blind test confirmed that no one had color blindness. This was essential because only participants with normal or corrected-to-normal vision could participate in the experiment. Furthermore, no participant had to be replaced due to failure in the pre-experimental part and no participant suffered from any neurological disease. The study was ethically approved by the Ethics Committee of the University of Twente.

2.2. Materials

The used experiment was programmed and displayed in “PyCharm Community Edition 2019.3.3 x 64” a development environment for “Python 3.8.” on a Windows 10 laptop. The experiment was presented afterwards on a 14-inch screen with a resolution of 1366 x 768 pixels. Participants viewed the presented stimuli from a distance of 40 to 50 cm. In addition, the test from EnChroma[1] was used to assess whether participants suffered from color blindness.

Stimuli for color and orientation were presented in a circle with gratings of 4.5° radius. Therefore, the stimuli set size for color contained 50 colors ranging from -105 hue to -56 hue. All colors were collected from HSV color space with a difference of one hue per color (Fig. 1). The intensity of saturation per color was not manipulated and stayed constant. Moreover, orientation stimuli rotated clockwise around one degree per stimuli, starting with 19 degree to a degree of 79 (Fig. 1).

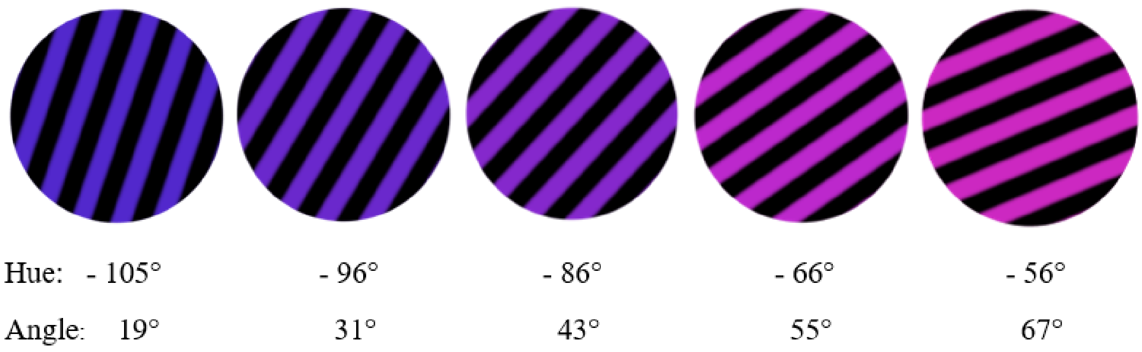

Figure 1: Examples of the used stimuli for color and orientation

2.3. Procedure

Before the start of the experiment, the participants read and signed the informed consent form after all instructions were given and all questions were answered. Six different versions of the experiment were employed. While the first part of the experiment (the pre-experimental period) was the same for all participants, a difference was implemented for the second part of the experiment. Thus, participants were assigned to one of the six versions according to their participant number. Thereby, the first participant received the first version, the second participant the second version and so on.

2.3.1. Pre-experimental period

Within the pre-experimental period, the individual participant's color and orientation sensitivity were tested. During this part, participants had to determine five colors and orientations that they could just distinguish from each other. Participants had to complete the color sensitivity part first before they could continue with the orientation sensitivity part. At the start, participants

[1] https://enchroma.com/pages/test

saw only a fixation cross in the middle of the screen. The first circle appeared to the left of the fixation cross for 1000 ms, followed by a second circle to the right of the cross, also for 1000 ms. The distance from the fixation cross to each circle was always about 1.5 cm.

The shown colors differentiated by one hue. Thus, the first circle presented the color of -105 hue while the second circle displayed had the color -104 hue. After the presentation of the two circles, participants were asked if the colors were different. Using the arrow keys participants could answer the question (left arrow key = the colors were the same; right arrow key = the colors were different) (Fig. 2). In the case that the answer was that the colors were the same, the second stimulus increased by one hue. Consequently, the colors -105 hue and -103 hue were presented. This process continued until the participant reported that the stimuli were different. Participants had to indicate that the colors were different four times before it was added to their personal color list.

The same procedure was repeated to determine the next stimulus. The next starting stimulus was the stimulus which was last added to the individual list. This stimulus increased again by one hue until the difference was noticed. Most importantly, the orientation during the color sensitivity part stayed constant with an angle of 0°. This also applied to color within the orientation sensitivity part in which the color did not change. Overall, the same selection procedure applied for the creation of the orientation list as well. The first stimulus started with an angle of 19° and increased about one degree for each presented stimulus. After the creation of both feature lists, the second phase of the experiment began using the selected stimuli.

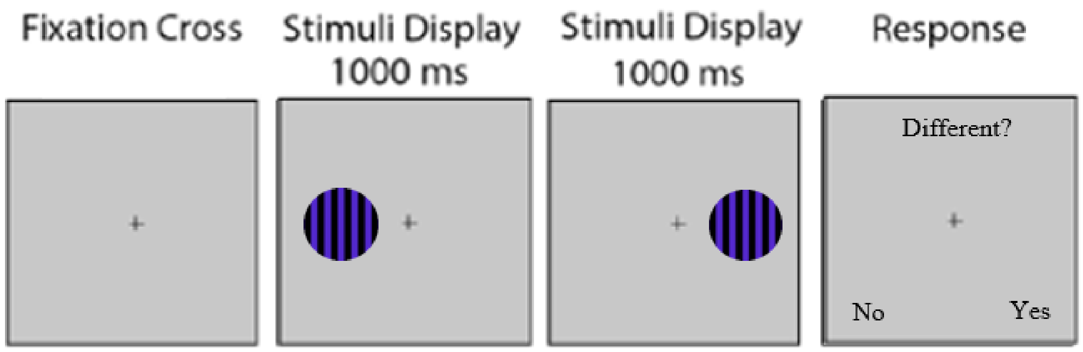

Figure 2: Illustration of the color sensitivity task with the colors -105 hue and -104 hue.

2.3.2. Experimental period

In the second phase, participants had to complete three attention condition blocks, namely: two focus attention condition blocks (one per feature) and one divided attention condition block in which both features could have been relevant. Depending on which version participants were assigned to, the order of the given attention conditions changed. Importantly, each version of the experiment consisted of 540 trials, generated by 180 trials per attention condition. Attention conditions were again divided into three subgroups determined by set size, which made 60 trials per subgroup. The set size could be either one, two, or four presented circles. The order of the subgroups was randomized.

At the start of each block, participants were told what feature they should focus on. To clarify the task, the participant had the chance to familiarize themselves with the task by completing five practice trials per instruction. Overall, the procedure was always the same. It started with the display of the fixation cross for about 1000 ms. Afterwards, either one, two, or four circles were presented for 2000 ms, followed by a delay for about 1000 ms in which participants saw the fixation cross only. Participants were then asked to read a prompt. The prompt asked which feature (color or orientation) had they seen prior within the dark grey area. All possible answers were presented at the bottom of the screen. Consequently, for the color instruction, the five colors from the individual list were presented while for the orientation condition, the five selected orientations were visible. For the divided attention condition, the available answers were either the five colors or orientations depending on what was asked for. It was randomly assigned whether the prompt asked for color or orientation for the last condition. Using the keyboard numbers, 1 to 5, participants were able to select their answer. Lastly, participants received feedback on whether they had chosen the right feature or not (Fig. 3). After a block was completed, participants were given a five-minute break. The process was then repeated, each new block beginning with the instruction for the practice trials followed by the relevant trials.

After the end of the experiment, participants were asked to fill out a small demographical questionnaire, which asked for gender, age, educational background, nationality, handedness, if they wore glasses, and whether they had or have any neurological disorders (see Appendix C). The whole experiment, including the color blind test and the small questionnaire, took approximately 2 hours.

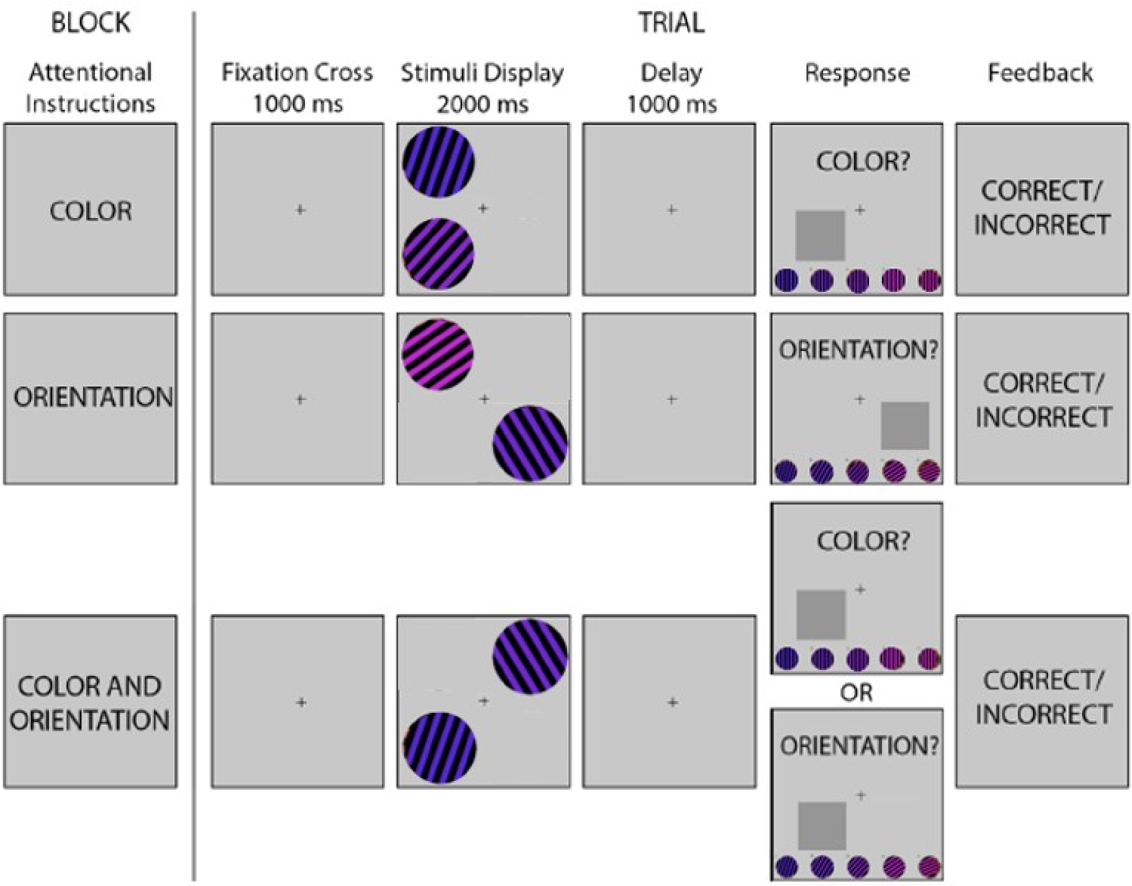

Figure 3: Illustration of the visual working memory task for experiment version one with two stimuli displayed.

2.4. Data analysis

2.4.1. The difference in feature sensitivity

The data was analyzed with the statistical program IBM SPSS Statistics 24. Descriptive statistics were used to visualize individual difference per group in feature perceptions which was determined within the pre-experimental period. Thereby, the distance between the first and last chosen feature is displayed in a scatterplot. A lower distance indicates that the participant had a higher ability to discriminate the feature.

2.4.2. Above chance performance

For both age groups a separate one-sample t-test was used to test whether participant's performance was above chance. Therefore, the error distances of the 12 conditions were tested against the average error distance of 1.6. The average distance was calculated by taking the mean score of all possible error distances ((2+1.4+1.2+1.4+2): 5 = 1.6). Before a one-sample t-test could be carried out, the following assumptions had to be met: no outliers, independence of data, the dependent variable should be measured on a continuous level and should be normally distributed.

2.4.3. The visual working memory task

This study used a four-way mixed ANOVA design with three within-subject factors and one between-subjects factor to analyze the impact of set sizes, features, attention conditions and age on the recall ability. Thereby, set size with three levels (1 vs. 2 vs. 4), features with two levels (color vs. orientation) and attention condition with two levels (focus vs. divided) were the within-subject factors. The between-subject factor was the age group (young adult group vs. middle-aged group). Since multiple comparisons were made, a post hoc test was implemented with a Bonferroni correction.

3. Results

3.1. The difference in feature sensitivity

Figure 4 visualizes the distance in the chosen feature for the middle-aged group. It can be observed that the distance between the first and last chosen color is smaller for four participants only, while the other three participants needed a lower distance between the first and last chosen orientation. However, participants needed a larger distance to distinguish between the first and last chosen orientation ($M_{\text{diff}} = 26.43$, $p = 0.024$) than for color ($M_{\text{diff}} = 17.57$, $p < 0.001$).

Figure 5 visualizes the distance in the chosen feature for the young adult group. The figure shows that the distance between the first and last chosen color ($M_{\text{diff}} = 17.1$, $p < 0.001$) is much smaller than for orientation ($M_{\text{diff}} = 34$, $p < 0.001$) with an exception for participant 8. Thus, the majority of the participants needed a larger distance to distinguish orientation features from each other than for color features.

To conclude, participants of both groups differ highly in their ability to distinguish between different colors or orientations. Moreover, results indicated that both groups needed a lower distance to distinguish different colors for each other than for orientation features. However, the young adult group needed a slightly smaller distance to distinguish between the first and last chosen color in comparison to the middle-aged group ($M_{\text{diff}} = 17.1$ vs. $M_{\text{diff}} = 17.57$) while the middle-aged group needed a smaller distance to distinguish between the first and last chosen orientation ($M_{\text{diff}} = 26.43$ vs. $M_{\text{diff}} = 34$).

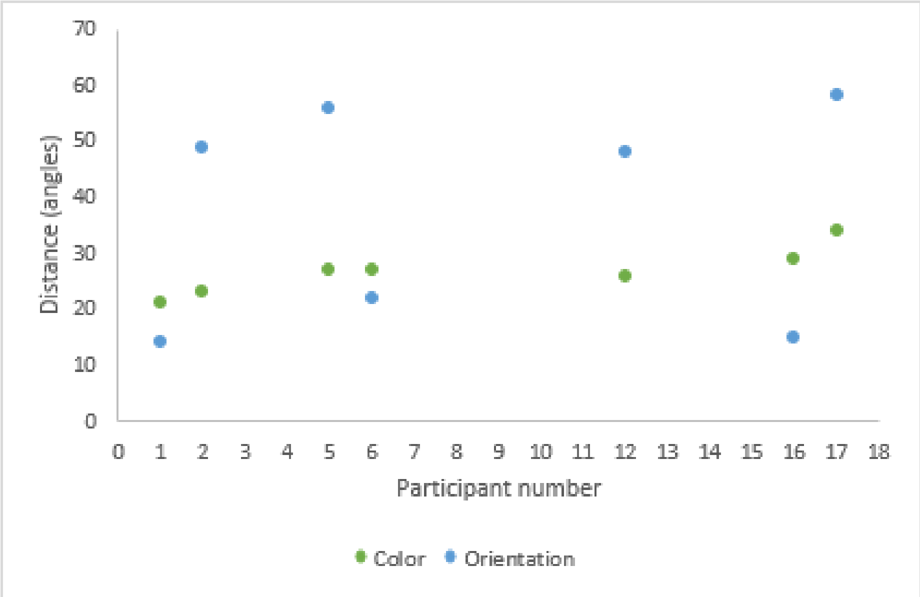

Figure 4: Distance between the first and last chosen feature for both color and orientation sets within the pre-experimental period for the middle-aged group

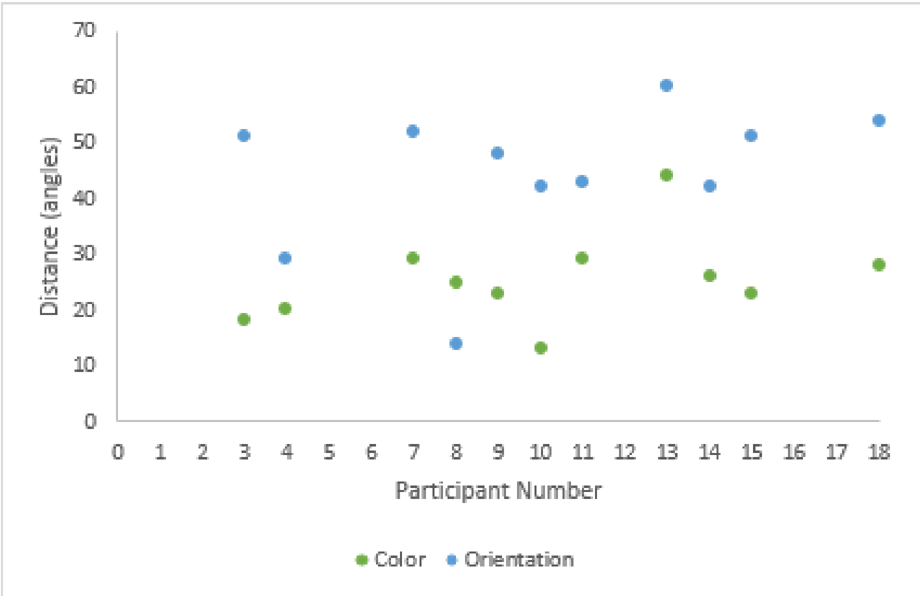

Figure 5: Distance between the first and last chosen feature for both color and orientation sets within the pre-experimental period for the young adult group

3.2. Above chance performance

A one-sample t-test was run for both age groups to determine whether the mean error distances for the 12 conditions were different from chance, defined as an average error distance of 1.6. Since the assumption of no outliers was not met, the outliers have been removed from the data set. Performances in all 12 conditions were significantly better than predicted by chance because of significantly lower error distances for both age groups. The largest mean error difference for the young adult group was found in the focus attention color condition with one stimulus (M_{diff} = -1.36, t (10) = -31.36, $p < 0.001$ (95% confidence interval [CI: -1.45; -1.26])). The smallest divergence for the young adult group was found in the divided attention orientation condition with four stimuli (M_{diff} = -0.4, t (9) = -6.18, $p < 0.001$ (95% confidence interval [CI: -0.54; -0.25])). For the middle-aged group the largest divergence was found in the focus attention color condition with one circle (M_{diff} = -1.3, t (6) = -14.84, $p < 0.001$ (95% confidence interval [CI: -1.52; -1.09])) and the smallest mean error distance was found in the focus attention orientation condition with four stimuli (M_{diff} = -0.32, t (6) = -2.63, $p = 0.04$ (95% confidence interval [CI: -0.61; -0.02])). Consequently, it can be concluded that the participants were not guessing.

3.3. The visual working memory task

A four-way mixed ANOVA was conducted to detect the influence of set size, features, attention conditions and age on the recall ability. Set size, features and attention condition were used as the within-subject factors and age as the between-subjects factor. Levene's test and normality checks were carried out and the assumptions met. The assumption of sphericity was violated for set size and therefore, adjusted values (Greenhouse-Geisser) were used for set size.

A main effect was found for set size on error distance, F (1.44, 23) = 66.23, $p < 0.001$, $\eta_p^2 = 0.81$. Comparing the estimated marginal means showed that recall performance on the four-circles condition was worst ($M = 0.94$, $SD = 0.06$; CI [0.82, 1.06]) compared to the two-circles condition ($M = 0.73$, $SD = 0.04$; CI [0.64, 0.83]) and one-circle condition ($M = 0.43$, $SD = 0.04$; CI[0.34, 0.52]). Post hoc tests showed that performance in all set sizes was significantly different from each other. The largest difference was found between set size 1 and 4 ($M_{\text{diff}} = 0.51$, $p < 0.001$) and the smallest difference between set size 2 and 4 (($M_{\text{diff}} = 0.2$, $p < 0.001$).

Furthermore, a main effect was found for features on error distance, F (1, 16) = 87.24, $p < 0.001$, $\eta_p^2 = 0.85$. Thereby, participants experienced more difficultly when they were asked to focus on orientation ($M = 0.88$, $SD = 0.04$; CI [0.79, 0.97]) than on color ($M = 0.52$, $SD = 0.05$; CI [0.41, 0.62]). Moreover, post hoc tests showed a significant difference for features. Participants could best remember color ($M_{\text{diff}} = 0.36$, $p < 0.001$).

There was also a notable main effect of attention condition on error distance, F (1, 16) = 71.45, $p < 0.001$, $\eta_p^2 = 0.82$. Estimated marginal means further indicated that participant's performance was better in the focused attention condition ($M = 0.6$, $SD = 0.04$; CI [0.51, 0.69]) in contrast to the divided attention condition ($M = 0.8$, $SD = 0.04$; CI [0.71, 0.89]). The conducted post hoc test indicated, that between focus attention condition and divided attention condition, there was also a significant difference 0.199 ($p < 0.001$).

Lastly, there was no significant main effect of age group on error distance, F (1, 16) = 1.89, $p = 0.19$, $\eta_p^2 = 0.11$. However, a significant interaction effect was found between age group and attention condition, F (1, 16) = 7.43, $p = 0.02$, $\eta_p^2 = 0.32$. Findings for the focus attention condition revealed that the performance of the young adult group was significantly better in the focus attention condition compared to the middle-aged group ($M = 0.51$, $SD = 0.05$ vs. $M = 0.69$, $SD = 0.07$, $M_{\text{diff}} = 0.18$, $p = 0.05$). Nonetheless, both age groups were significantly better in the focus attention condition compared to the divided attention condition with the largest mean difference for the young adult group ($M_{\text{diff}} = 0.26$, $p < 0.01$ vs. $M_{\text{diff}} = 0.14$, $p = 0.002$). Results of the divided attention condition showed that young adults were not significantly better in the divided attention condition compared to the middle-aged group ($M = 0.77$, $SD = 0.05$ vs. $M = 0.82$, $SD = 0.07$; $M_{\text{diff}} = 0.05$, $p = 0.58$). Further analysis, revealed that age has a significant effect on focus attention condition, F (9, 98) = 2, $p < 0.05$.

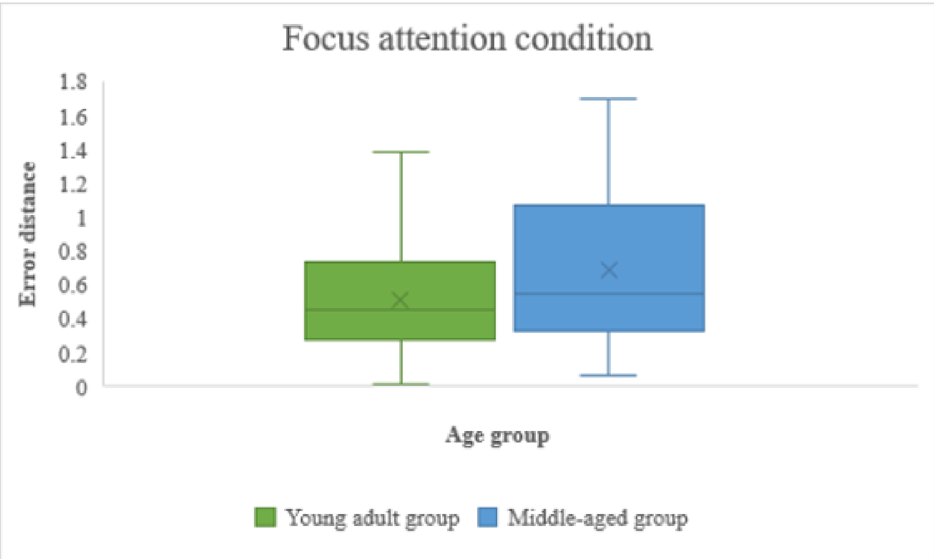

Figure 6: Visualization of performance in the focus attention condition for both age groups. The young adult group performed significantly better than the middle-aged group

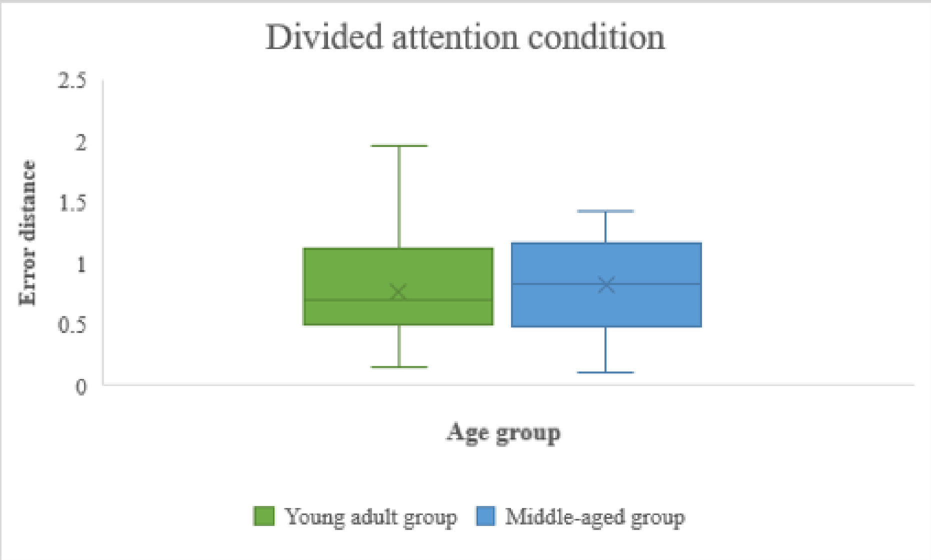

Figure 7: Visualization of performance in the divided attention condition for both age groups. There is no significant difference in group performance

Another interaction effect was found between age group, attention condition and set size, F (2, 32) = 3.63, p = 0.04, η_p^2 = 0.19. Pairwise comparisons for age groups showed that the performance of young adults and middle-aged people were not significantly different from each other with one exception. The young adult group performed considerably better in focus attention condition with set size two compared to the middle-aged group (M = 0.511, SD = 0.07 vs. M = 0.74, SD = 0.08; M_{diff} =0.22, p = 0.05). Overall, young adults performed best in the focus attention condition for set size one (M = 0.33) compared to performance for set size two (M = 0.51; M_{diff} = 0.18, p = 0.008) and set size four (M = 0.69; M_{diff} = 0.36, p = 0.001). Middle-aged participants were also best in the focus attention condition for set size one (M = 0.37) compared to set size two (M = 0.74; M_{diff} = 0.37, p < 0.001) and set size four (M = 0.95; M_{diff} = 0.58, p < 0.001). Consequently, recall preciseness declined when set size increased. Furthermore, recall preciseness was higher in the focus attention condition compared to the divided attention condition across conditions.

Moreover, an interaction effect between set size and features was observed, F (2, 32) = 10.7, p < 0.001, η_p^2 = 0.4. Results revealed that color was better remembered across different set sizes. For set size one, the error distance for color was 0.32 and the error distance for orientation was 0.53 (M_{diff} = 0.21, p = 0.002). Similarly, color was better remembered for set size two (M = 0.56 vs. M = 0.91; M_{diff} = 0.35, p < 0.001) and for set size four (M = 0.67 vs. M = 1.20; M_{diff} = 0.53, p < 0.001). Moreover, results revealed that error distance got larger as set size increased for each feature.

A last significant interaction effect was found between set size, features and attention condition, F (2, 32) = 5.44, p = 0.01, η_p^2 = 0.25. For set size one, color was better remembered than orientation in the focus attention condition (M = 0.27 vs. M = 0.43; M_{diff} = 0.16, p = 0.02) and in the divided attention condition (M = 0.37 vs. M = 0.64; M_{diff} = 0.26, p = 0.003). Similarly, for set size two, color was also better remembered than orientation in the focus attention condition (M = 0.47 vs. M = 0.78; M_{diff} = 0.31, p < 0.001) and in the divided attention condition (M = 0.64 vs. M = 1.04; M_{diff} = 0.4, p < 0.001). Lastly, color was also better remembered for set size four in the focus attention condition (M = 0.49 vs. M = 1.15; M_{diff} = 0.66, p < 0.001) and in the divided attention condition (M = 0.85 vs. M = 1.25; M_{diff} = 0.4, p = 0.004) compared to orientation. Consequently, color was always better remembered than orientation across different conditions. Furthermore, recall preciseness was better in the focus attention condition compared to the divided attention condition. Lastly, results revealed that with increase set size recall preciseness declined.

4. Discussion

The goal of the study was to investigate if and how age affects VWM function for middle-aged people and young adults. The inhibitory-deficit hypothesis suggests that age affects the filtering abilities which are essential in the focus attention condition (Hasher & Zacks, 1988; Jost et al., 2011). Therefore, middle-aged people should perform worse in the VWM task, especially in the focus attention condition compared to young adults, due to a decline in the suppression of irrelevant features. The hypothesis further presupposes that attention condition has an influence on VWM function. According to recent research, the LR model can best explain VWM function (Schneegans & Bays, 2019; Van den Berg et al., 2019; Van der Lubbe et al., 2019). The LR model predicts that attention condition and set size have an impact on recall preciseness. Results of this study revealed that age does not affect VWM function but the interaction between age and attention condition does. Therefore, the current findings confirm the inhibitory-deficit hypothesis. Moreover, attention condition, features and set sizes have an effect on recall preciseness. Consequently, findings are in line with the current assumption that the LR model can best explain VWM function.

4.1. The influence of age

Results revealed that age does not have a significant effect on recall ability even though the young adults' performance was overall better compared to the middle-aged participants. However, a significant interaction effect between age and attention condition was found. Young adults were significantly better in the focus attention condition but not in the divided attention condition compared to the middle-age group.

Results are best explained by the inhibitory-deficit hypothesis, which suggests that the elderly experience a decline in filtering abilities which are essential in neglecting irrelevant information (Hasher & Zacks, 1988; Jost et al., 2011). Further support for this finding comes from electroencephalography studies which reported a decline in the frontal lobe activity for elderly people (McNab & Klingberg, 2008; Van der Lubbe & Verleger, 2002). McNab and Klingberg (2008) determined that frontal lobe activities are essential for the mechanism to filter irrelevant information. Consequently, older participants should perform better in the divided attention condition compared to the focus attention condition.

This was not the case in the present study, since middle-aged participants were better in the focus attention condition compared to the divided attention condition. However, results also proved that young adults perform significantly better in the focus attention condition compared to the middle-aged group. Multiple researchers conclude that recall preciseness declines throughout the ageing process (Chen et al., 2003; Jost et al., 2011; Myerson et al., 2003; Vogel et al., 2005). This leads to predicting, that middle-aged people will score even lower in 10 or 20 years. Nonetheless, a decline is already observable within the middle age years.

Additional support for the inhibitory-deficit hypothesis comes from the finding that age has a significant effect on focus attention condition but not on divided attention (Jost et al., 2011). Suppression of irrelevant information appears to be highly important within the focus attention condition. According to the inhibitory-deficit hypothesis, these abilities decline throughout the ageing process (Jost et al., 2011; Vogel et al., 2005). Consequently, the result that age affects attention condition is best explained by the inhibitory-deficit hypothesis.

A last substantiating finding that showed that age affects VWM function came from the examination of the performance of participant 2 from the middle-aged group. This participant showed guessing behavior twice, namely in both focus attention conditions with four stimuli. However, the participant did not show guessing behavior in the divided attention conditions with four stimuli. Consequently, the performance of participant 2 is a good example to indicate that middle-aged participants experience more difficulties in the focus attention condition, as it is suggested by the inhibition-decline hypothesis. Overall, results cannot be explained by differences in perception, as the pre-experimental period controlled for this factor.

4.2. Visual working memory function

Recent research favors the LR model, which presumes that attention condition, set sizes and features have an effect on recall preciseness. Results of the present study are line with the current assumption that the LR model can best explain VWM function. Therefore, results demonstrated that attention condition, feature and set size have an effect on participant´s recall abilities.

In detail, participants were better in retaining a certain feature if they were instructed to focus on it. Consequently, focus attention enhanced recall abilities while divided attention decreased it. Support for this finding comes from a study by Machizawa und Driver (2011) who assumed a correlation between the preciseness with which an object is encoded and maintained, and the ability to focus one´s attention towards an object. Moreover, research on VWM revealed that focus attention helps in retaining a feature better because other features are ignored (Makovski & Jiang, 2007). More precisely, the study showed that in the case of divided attention, the chance of interference increased since multiple features were encoded.

Additionally, results showed that color was better remembered than orientation, which prompts to suggest that each feature has a separate capacity to be remembered. Thereby, feature independence was promoted. A study by Wang et al. (2017) manipulated different set sizes within their study to test the effect of set sizes for different features (orientation and color). Thereby, they concluded that set sizes correspond differently to each feature. This gave the impression that recall abilities are highly dependent on features. Furthermore, it was concluded that there is a higher likelihood to forget rather one feature than the whole object (Fougnie & Alvarez, 2011).

Lastly, results of set size showed that participant's recall performance was best when only one item was shown. An increase in set size consequently lead to a decrease in retaining new items. This finding pointed out that recall abilities are limited and that recall preciseness is dependent on the number of objects. Support for the limitation of VWM capacity comes from Cowan (2001) who concluded that one can only hold three to four pieces of information at any given time.

Furthermore, four above chance performances were identified for the set size of four. This outcome supports Van der Lubbe et al. (2019)'s proposal that the limit is reached before the set size of four items. Nonetheless, several researchers determined that VWM capacity varies among individuals (Astle & Scerif, 2011; Cusack, Lehmann, Veldsman, & Mitchell, 2009; Vogel et al., 2005). This would explain why some participants showed guessing behavior for set size four while others did not.

4.3. Study limitations and amendments for future studies

The study revealed several findings. First, the study found an effect of the interaction between age and attention condition on recall preciseness. More precisely, age affected the focus attention condition. Middle-aged participants' performance was significantly worse within the focus attention condition compared to young adults. This leads to suggesting that middle-aged people experience a deficit in VWM function already because they are less able to suppress irrelevant information. Additionally, results showed that attention conditions, features and set size influenced recall performance. Consequently, VWM function was best explained with a combination of the LR model and the inhibitory-deficit hypothesis.

A limitation of the study that might affect results was the length of the study. The study took approximately two hours which in the eyes of most participants was too long. Most of the participants reported that they experienced a concentration loss during the last block of the experiment. Therefore, it seems advisable to reduce the number of trials. Furthermore, the current COVID-19 situation increased the stress level of each participant. Thus, participants were asked to wear gloves and a mask which might affect performance as well. Finally, the set size was rather small after sorting participants according to their age. Therefore, an increased sample size would bring more reliable, precise, and authoritative results.

It is, therefore, advisable for future studies to repeat the experiment with a larger sample size. Furthermore, a third age group should be created to bring evidence that VWM function starts to change within the middle ages. Thus, VWM function should be tested and compared for young adults, middle-aged, and elderly people. Thereby, the following assumption should apply: First, young adults should perform significantly better than elderly, as it is predicted by literature; second, the difference between the young adult group and the middle-aged group should not be significant but young adults´ error distance should be lower; and third, middle-aged people should perform better than elderly but not significantly. Additionally, the use of EEG measurements while completing the experiment would manifest how age affects VWM function.

5. Conclusion

Results of the present study revealed that the interaction between age and attention condition affect VWM function, as it was predicted by the inhibitory-deficit hypothesis. In detail, an effect of age on focus attention was found, which indicates that the needed filtering abilities decline throughout the ageing process. Consequently, as one gets older the more the recall preciseness declines because of a deficit in suppressing irrelevant information. Interestingly, a decline in recall preciseness can already be detected within the middle ages. Furthermore, results revealed evidence that VWM function is best explained by the LR model, because attention condition, set size and features have an impact on retaining information. The more detailed results revealed that the feature color was better remembered than orientation in both age groups, which indicates the independency of feature capacity. Further, results on set size showed that one stimulus is best remembered and four stimuli worst. This finding manifests itself in both age groups. Lastly, performance in the focus attention condition is better than in the divided attention condition for both groups. To conclude, the combination of LR model and the inhibitory-deficit hypothesis can best explain VWM function for middle-aged people and young adults.

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Appendix A

Table 1. Report of RGB code and hue per color

Picture	RGB with Alpha 255	Hue
1.	82, 41, 204	-105
2.	84, 41, 204	-104
3.	87, 41, 204	-103
4.	90, 41, 204	-102
5.	93, 41, 204	-101
6.	95, 41, 204	-100
7.	98, 41, 204	-99
8.	101, 41, 204	-98
9.	103, 41, 204	-97
10.	106, 41, 204	-96
11.	109, 41, 204	-95
12.	112, 41, 204	-94
13.	114, 41, 204	-93
14.	117, 41, 204	-92
15.	120, 41, 204	-91
16.	123, 41, 204	-90
17.	125, 41, 204	-89
18.	128, 41, 204	-88
19.	131, 41, 204	-87
20.	133, 41, 204	-86
21.	136, 41, 204	-85

22.	139, 41, 204	-84
23.	142, 41, 204	-83
24.	144, 41, 204	-82
25.	147, 41, 204	-81
26.	150, 41, 204	-80
27.	152, 41, 204	-79
28.	155, 41, 204	-78
29.	158, 41, 204	-77
30.	161, 41, 204	-76
31.	163, 41, 204	-75
32.	166, 41, 204	-74
33.	169, 41, 204	-73
34.	171, 41, 204	-72
35.	174, 41, 204	-71
36.	177, 41, 204	-70
37.	180, 41, 204	-69
38.	182, 41, 204	-68
39.	185, 41, 204	-67
40.	188, 41, 204	-66
41.	190, 41, 204	-65
42.	193, 41, 204	-64
43.	196, 41, 204	-63
44.	199, 41, 204	-62
45.	201, 41, 204	-61
46.	204, 41, 204	-60

47.	204, 41, 201	-59
48.	204, 41, 199	-58
49.	204, 41, 196	-57
50.	204, 41, 193	-56

Appendix B

Information about the study:

By conducting this study, we try to bring new insights into how the visual working memory works. Our goal is to test whether attention conditions and different set sizes will have an effect on one´s recall abilities. Therefore, we designed a delayed- estimated task design for this experiment. Furthermore, we try to adjust the experiment to individual needs by tailoring the stimulus used. The whole experiment lasts approximately 1,5 hours and will be granted with two Sona points. Remark: In terms of good results, we would like to publish the results. Your data will be treated anonymously and you will be informed if this is the case.

Consent form:

I agree that I am voluntarily taking part in the study about the visual working memory for color and orientation by signing the consent form. I have been informed about the nature and method of the study and do not expect any benefit or payment for my participation. I am aware that I reserve the right to withdraw from the study at any time without giving an explanation. Furthermore, I have been informed that I have the right to request a copy of my results of the study. I am aware that in case of good results my data will be published. By signing the form, I give the researcher permission to publish my data on a later point. The researcher will inform me if this is the case. Otherwise the data will be automatically deleted after six months. I am aware that my data will be treated anonymously. The researcher is only allowed to give my personal data to third parties with my permission. Additionally, the researcher guarantees that there are no risks associated with the study. I know I am able to ask any question about the study and that all my questions have been and will be answered. If I request further information about the study, now or in future, I may contact Ioana Iliadis (i.p.i.iliadis@student.utwente.nl).

_____________________ _____________________ _____________________

Date and Place Signature Researcher Signature Participant

If you have any complaints about this research, please contact the secretary of the Ethics Committee of the Faculty of Behavioral Sciences at the University of Twente, Drs. L. Kamphuis-Blikman P.O. Box 217, 7500 AE Enschede (NL), telephone: +31 (0)53 4893399; email: ethicscommittee-bms@utwente.nl).

Appendix C

Questionnaire

Participant number (filled out by researcher): ________________________________

What is your gender?

Female: Male: Transgender:

How old are you?

____

What is your handedness?

Right-handed: Left-handed:

What is your nationality?

____

What is your educational background?

____

Do you wear glasses?

Yes: No:

Do you had or have any neurological diseases?

Yes: No:

Please indicate your email address:

____