The Influence of Age on Visual Working Memory

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Abstract

It is well known that working memory function declines with age. An explanation for this decline is the inhibitory-deficit hypothesis which states that the deterioration of working memory with age is due to a reduced ability to suppress irrelevant stimuli. While this effect is greatly researched in the elderly (60 years and upwards) it is not well inquired in middle-aged adults (40-60). Therefore, this study evaluated the visual working memory (VWM) of two age groups (a young adult group (18-25) and a middle-aged adult group (40-60)) with a delayed estimation task. To explain VWM function, and hence to be able to pin down the effect of age in the light of the inhibitory-deficit hypothesis on VWM in the best way, the two most popular models from the literature about VWM were used with the discrete capacity (DC) and the limited capacity model (LR). While for the DC model it is assumed that VWM consist of a firm number of slots to store information, for the LR model it is supposed that there is a limited amount of resources available to encode specific features of a stimulus.

The study revealed insignificant effects of age which were however partly in line with the inhibitory-deficit hypothesis, leading to inconclusive results. With regard to the explanation of VWM function, the number of stimuli and attention conditions exerted a significant effect on VWM leading to the conclusion that overall results were slightly better explained by the LR model than the DC model.

Table of contents

Introduction

The fact that visual working memory (VWM) declines during the process of ageing, is well researched (Jost, Bryck, Vogel, & Mayr, 2011; Vogel, McCollough, & Machizawa, 2005). Visual working memory in this regard is a part of the short-term memory system of the brain (Baddeley & Hitch, 1974; Markov, Tiurina, & Utochkin, 2019). It maintains visual information for a short amount of time with activity often found in the prefrontal and occipital cortex (Mayer, Bittner, Nikolić, Bledowski, Goebel, & Linden, 2007). However, it is not well researched when this age-related decline sets in. Although it is clearly evident in adults aged 60 or higher the evidence for middle-aged adults (40-60) is scarce. Therefore, this study will examine this closer by following up on a study of Illiadis and Van der Lubbe (2019) with the main aim to replicate their results of a decline for middle-aged adults next to other aims described later. For this, it is first important to understand the mechanisms behind this decline to then make inferences on potential hypotheses.

The age-related decline in old adults (60 and rising) is hypothesized to be related to the inability to suppress irrelevant stimuli, leading to an overload of memory capacity and consequently in a failure to retain information in short-term memory appropriately (Gazzaley, Clapp, Kelley, McEvoy, Knight, & D´Esposito, 2008; Jost et al., 2011). This is called the inhibitory deficit hypothesis and is based on the assumption that VWM has a limited capacity to handle stimuli. This idea is backed up by electroencephalographic studies from which it was concluded that older adults show worse filtering ability in a change detection task due to overall N1 and P1 amplitude latency suppression deficits, especially in the first few moments when stimuli are beginning to be stored. After that, individual differences are the ones that drive disparities in the storing process (Gazzaley et al., 2008; Jost et al., 2011). Due to replication purposes, this study will only focus on the filtering efficacy during the experiments that follow.

With regard to how the capacity of VWM is constituted, two models in the literature are popular these days - the discrete capacity model (DC) and the limited resource model (LR). The DC model proposes that VWM consists of several but limited “slots” in which information is stored (Cowan, 2001; Luck & Vogel 1997). In this model, it does not matter how complex the different stimuli are which are focused upon. As long as enough slots are available the representation of the stimuli in memory will be as equally as accurate for stimuli that have few characteristics (e.g., a brick) than stimuli that have lots of characteristics (e.g., a human). The LR model on the other hand is based on the idea that humans have a limited capacity available to encode several features of objects (Schneegans & Bays, 2019; Van den Berg, Zou, & Ma, 2019; Van der Lubbe, Borsci, & Miezyte, 2019; Wang, Cao, Theeuwes, Olivers, & Wang, 2017). Hence, the LR model assumes that the recall preciseness of stimuli resp. the representation of the object/stimulus in VWM declines if objects get more complex since resources will be depleted faster if a lot of features have to be encoded in comparison to only a few (Ma, Husain, & Bays, 2014; Markov et al., 2019). Like the inhibitory-deficit hypothesis, the LR model assumes that attention conditions have an impact on recall abilities because the LR model expects that there is a multitude of storages, each focusing on different features (e.g. one on colour, one on orientation) and each having demands for attention resources (Delvenne & Bruyer, 2004; Markov et al., 2019; Wang et al., 2017).

Earlier experiments on VWM preferred DC models focused on recall ability (how many items or features could correctly be remembered) and hence DC models (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001). However, more recent experiments tend to shift more and more towards recall preciseness (how accurately features or items could correctly be remembered) and hence LR models since they seemed to describe the data better (Ma et al., 2014; Schneegans & Bays, 2019; Van den Berg et al., 2019; Van der Lubbe et al., 2019; Wang et al., 2017). Especially with a larger set of stimuli, the age-related decline in VWM gets more visible regarding recall preciseness (Tas, Costello, & Buss, 2020). Unfortunately, not many experiments have been done with a set of stimuli that pushes the participants towards the maximum of VWM which lies at 3-4 items (DC model) or 3-4 features of a particular item (e.g. colour) (LR model) (Souza, 2016).

Until today, most studies focused on old adults (60 and rising) for their endeavours in proving the decline of VWM (Hasher & Zacks, 1988; Van der Lubbe & Verleger, 2002). However, a study by Crook and West (1990), also found a small but significant difference in recall preciseness between middle-aged participants (40-60) and young adults (18-25). However, not much research has been done since then on these to two age groups despite the studies that were carried out in this regard show confirmatory results to the study of Crook and West (1990). For example, a study by Iliadis & van der Lubbe (2020) showed that the interaction of age (being middle aged) and attention condition affects VWM function, adding to the evidence that there is already a decline in VWM for middle aged adults. In their study, they used a delayed-estimation task to measure VWM and to get a grip on the difference of LR and DC models in middle-aged adults. During a delayed-estimation task, participants are asked to affirm a certain feature (e.g. colour or orientation or both) from an object which was shown beforehand (Ma et al., 2014). Additionally, accounting for potential biases in perception, they included a pre-experimental period based on the studies of Van der Lubbe and colleagues (2019) and Tulver (2019) who found that participants' abilities to distinguish between different features differ largely from one another. Accordingly, the present study also made use of a delayed-estimation task with the inclusion of a pre-experimental period to rule out for effects of differences in perception for the two features used in this study (colour and orientation). This is important since if a set of uniform stimuli for all participants were used, some participants might have advantages in detecting the differences between stimuli during the delayed-estimation task, leading to faster memory consolidation, hence leading to better results. However, if an individual set of stimuli is used for every participant, enabled by the pre-experimental period, every participant has the same preconditions.

This study will improve on the study of Iliadis & van der Lubbe (2020) by including a larger sample size of middle-aged (40-60) and young adult (18-25) participants and using a set of 1 vs. 3 vs. 4 stimuli to focus on closing the gap in the literature regarding low stimuli sets and research on middle-aged adults on VWM.

As in the study of Iliadis & van der Lubbe (2020) it is hypothesised that the inhibitory-deficit hypothesis predicts an influence of age on the recall preciseness, especially in the focus attention condition (only focusing on one feature (e.g. only focusing on colour while disregarding orientation)), middle-aged participants should score lower on recall preciseness in the VWM task compared to young adults, especially in the focus attention condition. This hypothesis is in line with the inhibitory-deficit hypothesis since middle-aged adults are predicted to have difficulty suppressing the irrelevant feature in the focused attention condition leading to worse performance compared with the young adult group. Additionally, it is hypothesised that the recall preciseness of middle-aged adults will drop when the number of stimuli rises when compared to the young adults, especially for the divided attention condition since this effect was already seen in studies with old adults (60 upwards). This would be in line with the LR model since it would predict that the more features to focus on, the less precise the representation in VWM.

Methods

Participants

24 participants volunteered their time to take part in this study. A convenience sampling method was used to choose the participants and create two age groups (18-25 & 40-60). The first group, which in the following will be coined the young adult group, consisted of twelve participants with a mean age of 50.08 (*SD* = 3.73, german = 12, men = 5, women = 7). Eleven young adults were right-handed while one was left-handed. Five young adults wore glasses or contact lenses during the exercise.

The second group which in the following will be denoted as the middle-aged adult group, likewise, contained twelve participants with a mean age of 21.17 *(SD* = 2.04, polish = 1, dutch = 3, german = 8, men = 8, women = 4) from which six wore glasses or contact lenses during the study. All twelve middle-aged adults were right-handed.

Before each start of the experiment each participant reported having normal or corrected-to-normal colour vision. The Ishihara 38 plate colour blind test verified this, revealing that no participant had a form of colour blindness. No participant had a neurological disease. The study was ethically approved by the Ethics Committee of the University of Twente (Requestnumber: 220632).

Materials

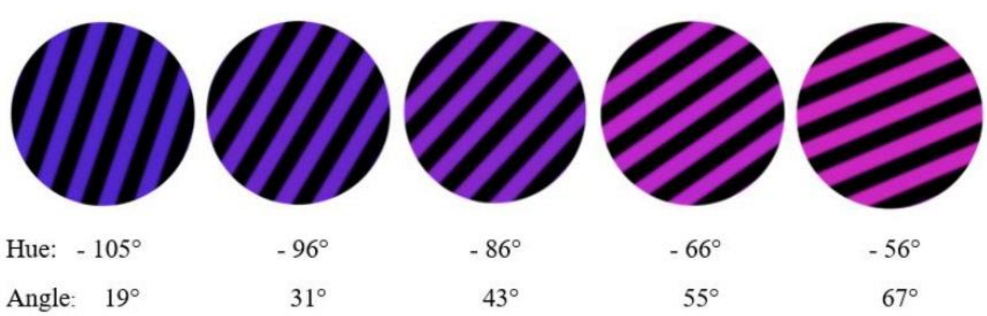
The main experiment (pre-experimental task and short-term memory task but not consent form, demographic questions, and colour blind test) was programmed and presented to the participants via "PyCharm Community Edition 2021.3.3" an Integrated Development Environment for Python 3.9.12 on an Acer Aspire E 15 (15.6 inch screen, 1366x768 resolution) with Windows 10.

Before the main experiment began, participants filled out an informed consent form, a short demographic questionnaire and the 38 plate Ishihara test, which was available on www.colorblindnesstest.org/ishihara-test/. The demographic questionnaire consisted of questions about age, nationality, and gender (see Appendix A). The informed consent included information about the aims, activities, burdens and risks of the research, how the data would be handled, how it is stored, how it is presented to others, and lastly that withdrawal from the study is possible at every moment in time (see Appendix A)

The stimuli used for the main experiment were identical to the ones from the study of van der Lubbe & Illiadis (2019). Hence, the sets for both colour and orientation contained 50 elements, retrieved from HSV colour space. All stimuli for colour and orientation were displayed in a circle with gratings of 4.5° radius. The 50 colours ranged from 105 to 56 hue (see Figure 1), whereby the saturation remained constant. Stimuli for orientation started at 19 degrees and finished at 69 degrees, rotating one degree per stimulus (see Figure 1).

Figure 1

Example Stimuli for the Experiment



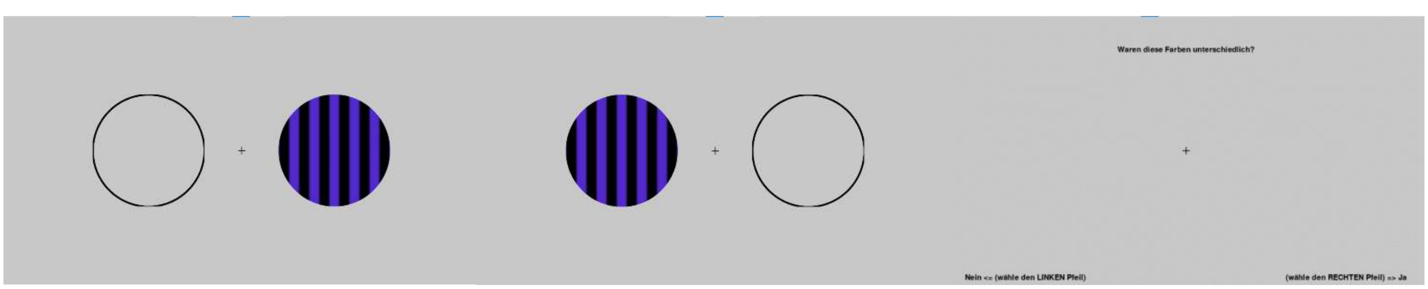
Procedure

*Pre-experimental p***art**

The pre-experimental period introduced the participants to a task that measured their individual sensitivity for colour and orientation. For both features (colour & orientation) participants had to distinguish five stimuli which were later used for the experimental period. First, all participants were presented with the colour section. Afterwards, the orientation section followed. At the start, participants saw only a fixation cross in the middle of the screen. The first circle appeared randomly to the left or to the right of the fixation cross for 1000 ms while on the empty side (left/right) a circle without any attributes was displayed to make sure that participants were not able to predict on which side of the screen to shift their attention to. These circles were followed by a second pair of circles (one with the colour attribute and an empty one) on the opposite side where their counterparts were shown before (if first, coloured circle left, empty circle right, then second, coloured circle right, empty circle left) (see Figure 2). The distance from the fixation cross to each circle was always about 1.5 cm. The shown colours at the start differed by one hue. This means that if the first presented coloured circle had a hue of -105 then the second one would have a hue of -104. However, it was always random which of the two coloured circles was displayed first so that also the -104 hue circle could be displayed primary to the -105 hue circle. After the presentation of the two coloured and two empty circles, participants were asked if the colours were different. Using the left and right arrow keys participants indicated if left: “the colours were the same,” and right: “the colours were different”. If the participant answered with the left arrow key (same colours), the difference between the two coloured circles was increased by one hue so that consequently after a press on the spacebar the coloured circles would show hues of -105 and -103. The difference between the two coloured circles was increased until the participant indicated that he/she was able to discriminate between the two colours (right arrow key). In order to ensure that participants were able to see a difference between the colours, the colours in question were presented three more times in which the participant had to press the right arrow key again so that the two colours would be added for usage for the experimental method. If the participant pressed the left arrow key during this period, the procedure continued as written above (increase by one hue). After two colours had been added to the experimental period, the next starting colour of a circle for the sensitivity task would be the colour of the circle that was last added to the experimental period. Then the procedure as stated above was repeated until five colours had been found as different. During the colour sensitivity section, the orientation of the circles remained constant at 0° while during the orientation sensitivity task the colour in the circles did not change (only orientation did obviously). In the orientation sensitivity section, the same procedure as in the colour sensitivity section was applied only that instead, the colour in the circles changed by one hue, the angle of the stripes changed by 1° if the participant pressed the left arrow key. After five orientation stimuli were discriminated by a participant the experimental period began.

Figure 2

Example of a Sequence for the Colour Sensitivity Test



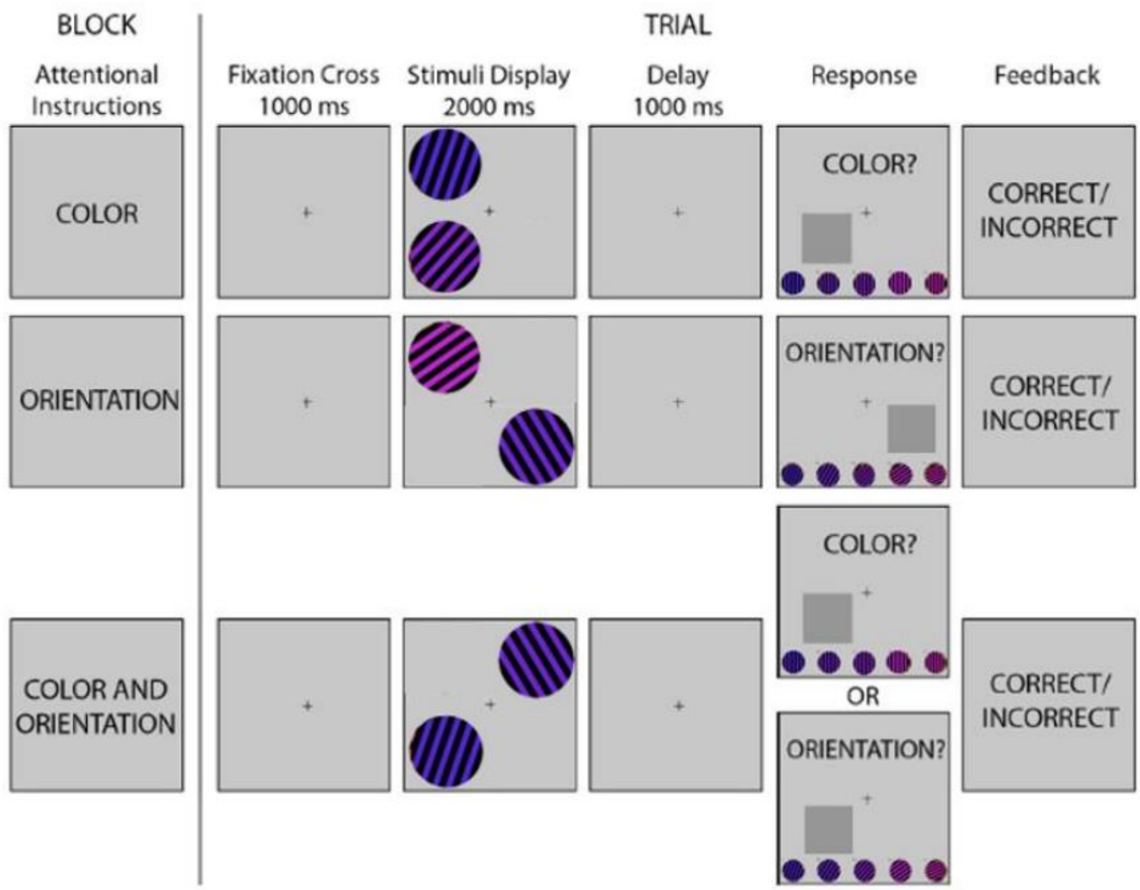
Experimental part

In the experimental period, participants were assigned to one of six versions according to their participant number. The first participant received version 1, the second participant version 2, participant 7 version 1 again and so on. The six versions were different in that the order of the attention conditions presented to participants were dissimilar. Version 1 for example started with colour, followed up by orientation, and concluded with the divided attention condition in which both stimuli were important, while Version 3 started with the divided attention condition, followed up by colour, and finally orientation.

During the experimental period, participants had to carry out a short-term memory task which was split into three different blocks. In each block, the participant had to focus one's attention on a different condition. There were two focused attention condition blocks (one per feature (colour & orientation)) and one divided attention condition block in which both features had to be focused on. In this regard, the participant number and hence the version the participant worked with, decided the order in which the three different attention condition blocks were presented. In total every experiment consisted of 540 trials with each attention condition block containing 180. These 180 trials per attention condition were then again split into 3 subgroups each entailing 60 trials. For every subgroup, a different number of circles was presented on the screen (1, 3 or 4). The order of the subgroups was randomized. At the start of each block, the program showed the participants which feature (colour, orientation, both) to focus on. In order to make sure that the participant understood the given task and had the opportunity to ask questions about it, five practice trials were given at the beginning of each block. If no questions remained, the experiment progressed. In general, the procedure was the same every time. At first, the screen displayed a fixation cross for 1000ms after which either one, three, or four circles were shown for 2000ms. These circles were the products of combining the circles from the orientation and colour sensitivity phase so that 25 circles were created (5*5). Each circle that was presented during a trial was displayed in one of the corners of the screen (see Figure 3). This presentation was followed by a gap of 1000 ms in which only the fixation cross was shown until a new page showed up. Here the screen displayed a prompt regarding which specific feature was seen in the dark grey marked area. The dark grey marked area was always on a spot where a circle was presented beforehand. Now the task of the participant consisted of the identification of the colour/orientation (depending on the condition that was asked for) of this circle in the grey marked area by choosing between 5 circles displayed on the bottom of the page whereby one of these circles entailed the correct feature that was asked for. During the colour attention block, the five identified circles from the colour sensitivity task were displayed as answer options, while for the orientation attention block, the five identified circles from the orientation sensitivity task were displayed as answer options. For the divided attention block, the answer options depended on the feature that was asked for in the prompt. It was randomly assigned whether the prompt asked for colour or orientation during the divided attention condition. Participants could indicate their choice for one of the five answer options by using the keyboard numbers, 1 to 5. After the participant selected an answer, they were given feedback if their answer was correct or not after every single trial. After a block was completed, the participants were obliged to take a five-minute break. This procedure was repeated until all three blocks were completed, and then the experiment ended. Most of the time the whole experiment (informed consent, colour blindness test, pre-experimental phase, experimental phase) took approximately slightly less than 2 hours.

Figure 3

Example of a Sequence in the Experimental Part of Experiment Version One for Two Stimuli



Data Analysis

Differences in feature sensitivity

The data was analyzed with the statistical program IBM SPSS Statistics 28. In order to get a better overview of the selected stimuli of the two age groups and hence their ability to discriminate between features, a scatter plot was used to display the distance between the first and last chosen feature for the two sensitivity trials (colour & orientation) from the pre-experimental phase.

Above chance performance

In order to ensure that no guessing behaviour was executed by the participants, a one-sample *t*-test was used to test whether the participant's performance was above chance. Therefore, the error distances of the 6 conditions (1, 3, 4 stimuli focused attention, 1, 3, 4 stimuli divided attention) were tested against the average error distance of 1.6. The average distance value was calculated by, first, determining all possible distances of a correct answer to an observed one (1-4). In a second step, the average of these distances for all potential combination was calculated ((2+1.4+1.2+1.4+2): 5 = 1.6).

So that a one-sample t-test is reasonable to be conducted the assumptions of “no outliers” and “normal distribution of variables” should be met. To account for outliers, boxplots of all the 6 conditions were created and extreme outliers removed from the dataset. Lastly, to ensure the normal distribution of the variables a Shapiro-Wilk normality test was executed for all relevant variables.

The visual working memory task

This study made use of a three-way mixed ANOVA design with two within-subject factors and one between-subject factor to analyse the individual impacts of set size, attention condition and age but also the interaction of all these factors on error distance. In this regard, set size with three levels (1 vs. 3 vs. 4) and attention condition with two levels (focus vs. divided) were the within-subject factors. The between-subject factor was age group with two levels (young adult group (18-25) vs. middle-aged group (40-60)). Before the data was ready to be analysed, it was examined for sphericity and variance assumptions by the Mauchly test (Sphericity) and Levene-Test (variance) so that the data for the three-way mixed ANOVA can be reliably interpreted. Additionally, the same analysis was conducted with age as a covariate rather than a between-subject factor to account for the fact that age was not randomized or controlled for in the experiment, to improve the accuracy of the following analysis.

Results

Differences in feature sensitivity

In general, participants were better in distinguishing colour in comparison with orientation (*Mdiff* = 29.63, $p < 0.001$ vs. *Mdiff* = 38.21, $p < 0.001$). More specific, the young-adult group was better in distinguishing colour from orientation (*Mdiff* = 30.33 vs. *Mdiff* = 40.75). The same is observable for the middle-aged group (*Mdiff* = 25.91 vs. *Mdiff* = 35.67). Furthermore, as visualised in Figure 4, it got apparent that the middle-aged group was better in distinguishing between colour stimuli in comparison to the young adult group (*Mdiff* = 30.33 vs. *Mdiff* = 25.91, $p = 0.06$). Also the discrimination between orientation stimuli in the pre-experimental phase was better in middle-aged adults than for young adults (*Mdiff* = 40.75 vs *Mdiff* = 35.67, $p = 0.25$), as displayed in Figure 5.

Figure 4

Comparison of the distance for the first and last chosen features for colour of the young and middle-aged adult group in the pre-experimental part. The higher the bar, the larger the distance

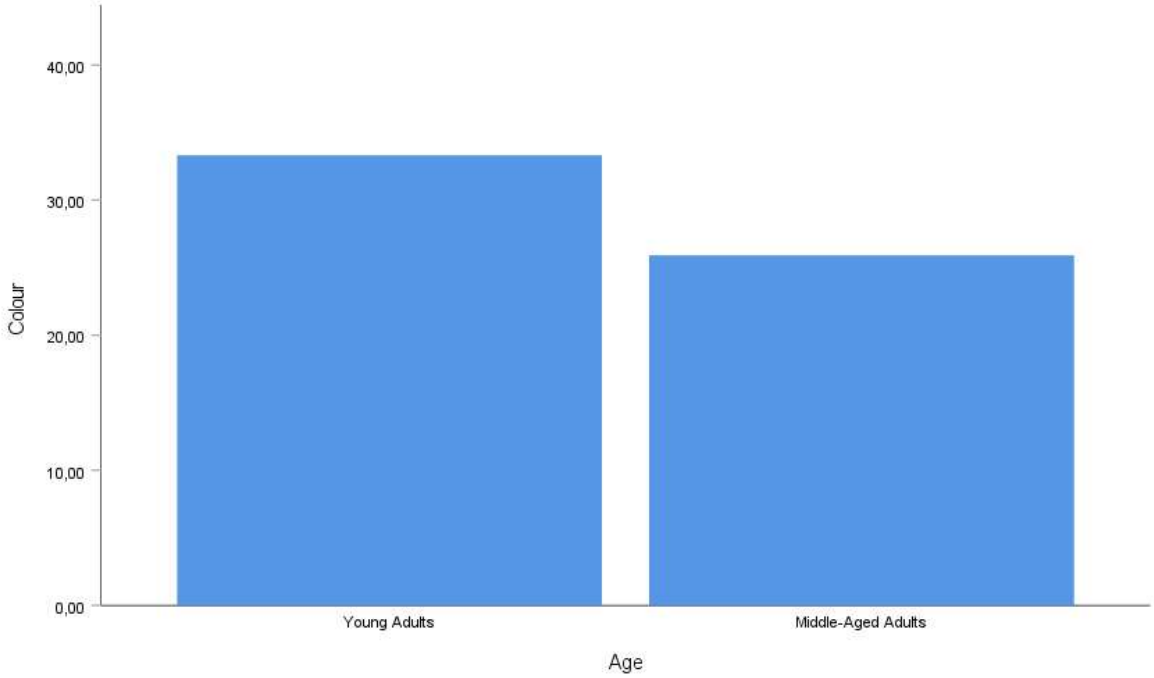
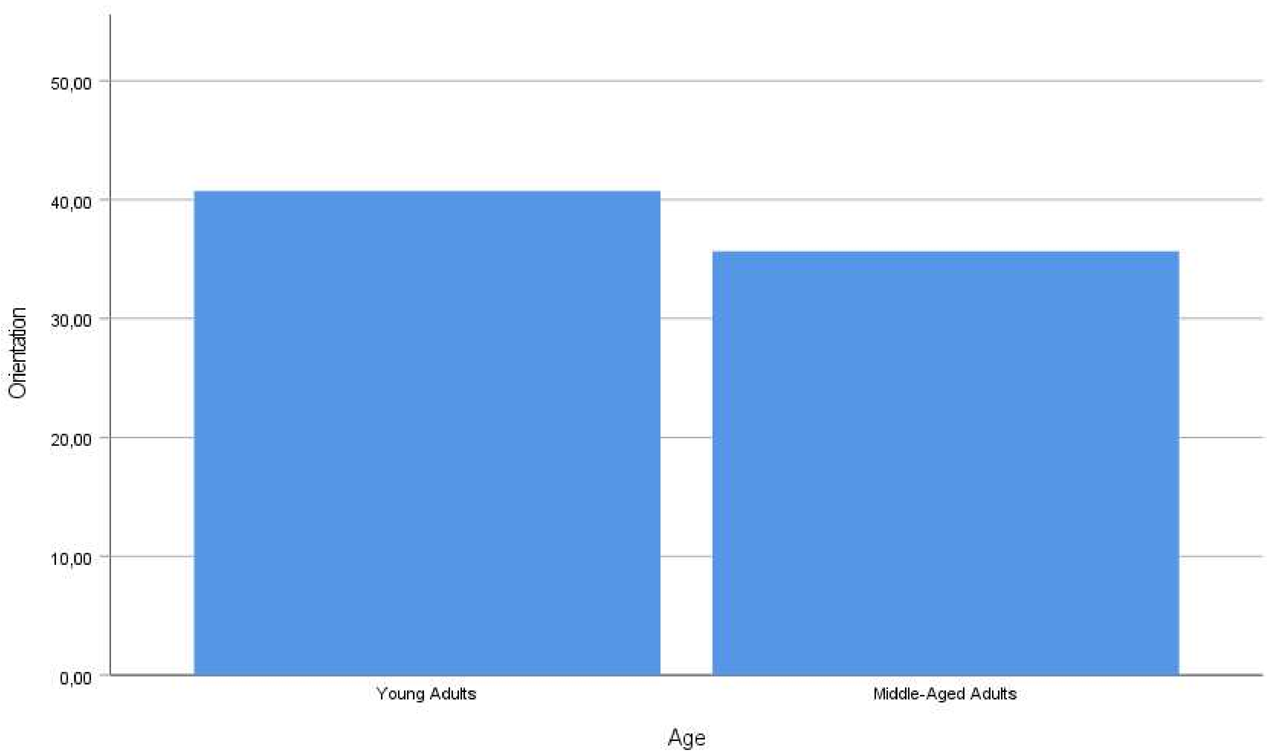


Figure 5

Comparison of the distance for the first and last chosen features for orientation of the young and middle-aged adult group in the pre-experimental part. The higher the bar, the larger the distance



Above chance performance

Assumptions for normality were met and no extreme outliers were identified, wherefore the *t*-test and the three-way mixed ANOVA were executed with no further changes to the dataset. The performances in all 6 conditions were significantly better than predicted by chance as significantly lower error distances for both age groups were observed. The largest divergence from chance was found for the focused attention condition with one stimulus (*Mdiff* = -1.16, $t(22) = -35.27$, $p < 0.001$ (CI [-1.22, -1.09]), while the lowest divergence from chance was displayed for the divided attention condition for four stimuli (*Mdiff* = -0.44, $t(23) = -9.41$, $p < 0.001$ (CI [-0.54, -0.35]). It can be deducted that the participants did not engage in guessing behaviour.

The visual working memory task

In this study only the assumption of variance was fulfilled while the assumption of sphericity was violated for the interaction of attention condition (AC) and set size. Therefore, adjusted values (Greenhouse-Geisser) were used for this interaction.

First of all, there was a main effect of attention condition on error distance $F\ (1, 22) = 60.88$, $p < 0.001$, $\eta_p^2 = 0.86$. Estimated marginal means further indicated that participant's performance was better in the focused attention condition (*M* = 0.728, *SE* = 0.35; CI [0.66, 0.8]) than in the divided attention condition (*M* = 0.95, *SE* = 0.31; CI [0.89, 1.02]).

Secondly, there was a main effect found for set size on error distance, $F\ (2, 44) = 132.78$, $p < 0.001$, $\eta p\ 2 = 0.86$. Comparing the estimated marginal means illustrated that recall performance on the one circle condition was best (*M* = 0.517, *SE* = 0.35; CI [0.45, 0.59]) compared to the three-circles condition (*M* = 0.97*, SE* = 0.35; CI [0.90, 1.05]) and four-circle condition (*M* = 1.03, *SE* = 0.37; CI [0.95, 1.11]). However, the executed post hoc test only showed that there was a significant difference between the error distances of set sizes one and three (*Mdiff* = 0.46, $p < 0.001$) and one and four (*Mdiff* = 0.51, $p < 0.001$) while there was no significant difference between set sizes three and four (*Mdiff* = 0.06, $p = 0.28$).

Thirdly, there was a significant interaction effect between set size and attention condition, F (1.56, 34.26) = 4.73, $p < 0.02$, $\eta_p^2 = 0.18$. Results revealed that set size one was best remembered across both attention conditions (Focused Attention Condition: $M = 0.44$, $SE = 0.3$ Divided Attention Condition: $M = 0.59$, $SE = 0.4$); in comparison to set sizes 3 (Focused Attention Condition: $M = 0.84$, $SE = 0.4$ Divided Attention Condition: $M = 1.11$, $SE = 0.4$) and 4 (Focused Attention Condition: $M = 0.90$, $SE = 0.4$ Divided Attention Condition: $M = 1.16$, $SE = 0.5$).

Finally, there was neither a significant main effect of age group on error distance, F (1, 22) = 0.01, $p = 0.78$, $\eta_p^2 = 0.04$, nor a significant interaction effect of age group with either set size F (1.66, 36.55) = 0.01, $p = 0.98$, $\eta_p^2 = 0.000$ or attention condition F (1, 22) = 2.87, $p = 0.10$, $\eta_p^2 = 0.12$ or both F (1.56, 34.26) = 1.24, $p = 0.29$, $\eta_p^2 = 0.05$ (see Appendix B).

However, the young adults scored better in the focused attention condition than the middle-aged adults ($M = 0.71$, $SE = 0.05$ vs. $M = 0.74$; *Mdiff* = 0.03), while they scored worse in the divided attention condition ($M = 0.99$ vs. $M = 0.92$; *Mdiff* = 0.07). With regard to size, the middle-aged adult`s results were better in comparison to the young adults for set size one ($M = 0.53$, vs. $M = 0.51$; *Mdiff* = 0.02). Besides, the middle-aged adults also scored better for set size 3 ($M = 0.98$ vs. $M = 0.97$; *Mdiff* = 0.01) and set size four ($M = 1.04$ vs. $M = 1.02$; *Mdiff* = 0.02), in comparison to the young adult group.

Figure 6

Visualization of error distance in the focus attention condition for the young and middle-aged group. The higher the bar, the lower the recall preciseness

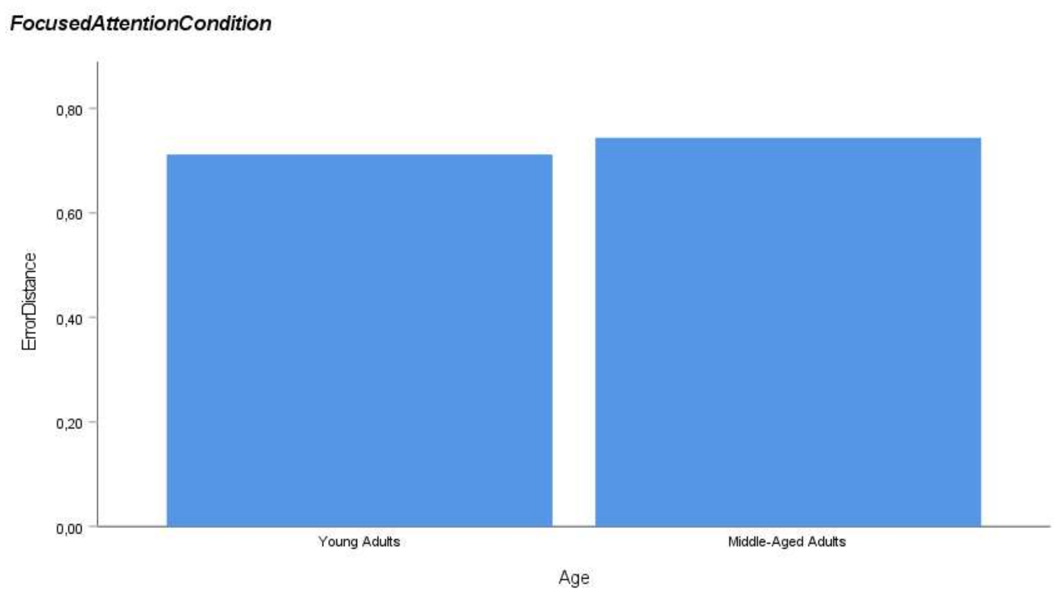


Figure 7

Visualization of error distance in the divided attention condition for the young and middle-aged group. The higher the bar, the lower the recall preciseness

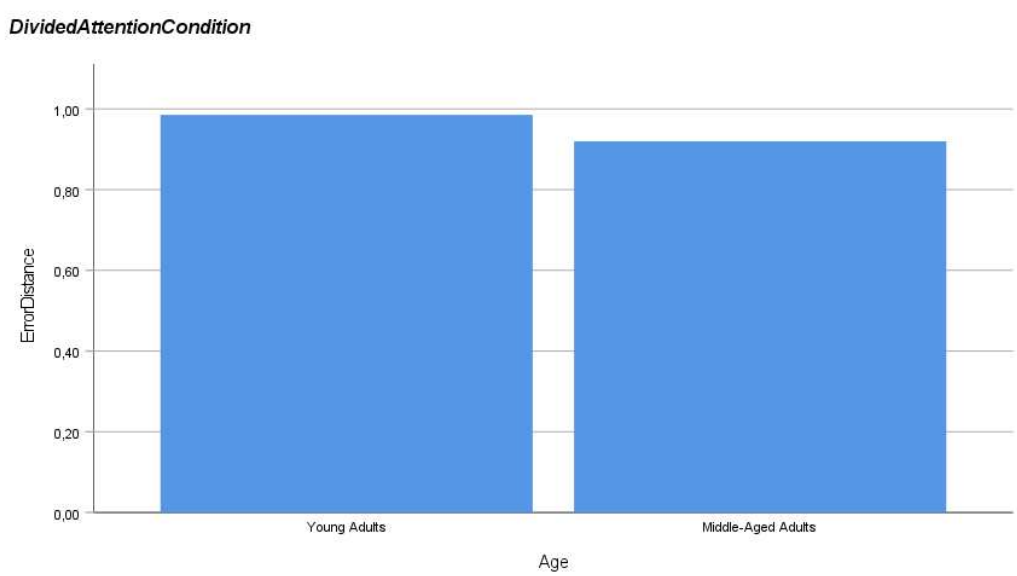
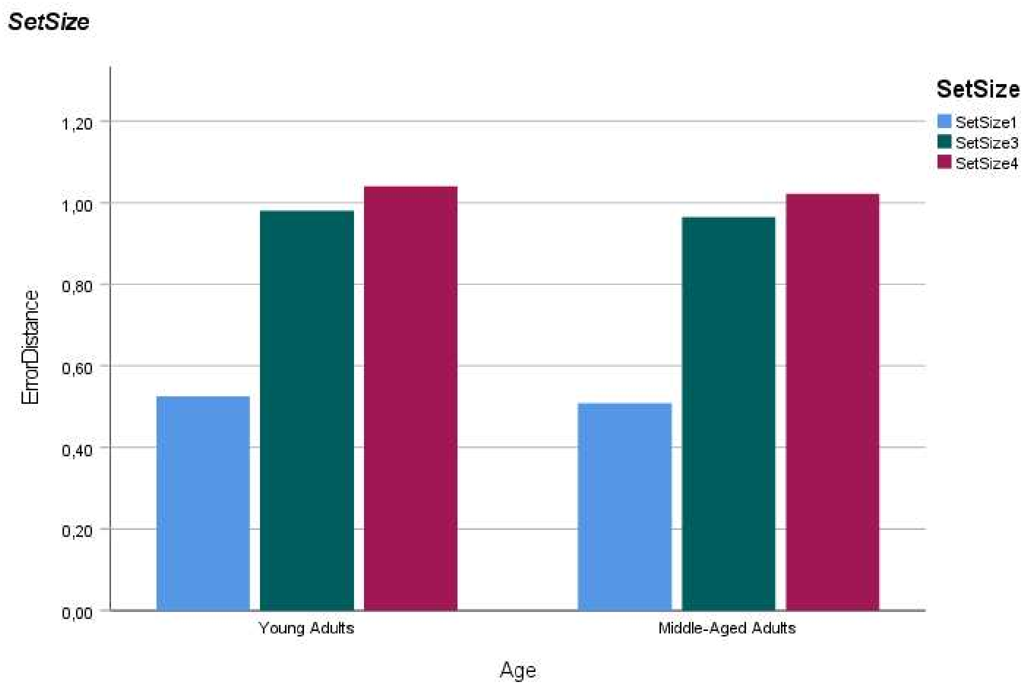


Figure 8

Visualization of error distance for the diverse set sizes for the young and middle-aged group. The higher the bar, the lower the recall preciseness.



For the covariate analysis, which was conducted as an additional analysis, there were no changes except for the disappearance of the interaction effect between attention condition and set size to insignificance, F (1.57, 34.62) = 2.80, p = 0.09, η_p^2 = 0.11. The effects of age remained insignificant. There was neither a significant interaction effect of age with set size, F (2, 44) = 0.04, p = 0.96, η_p^2 = 0.002, nor and interaction effect with attention condition F (1, 22) = 2.27, p = 0.15, η_p^2= 0.09 or both F (1.57, 34.62) = 0.88, p = 0.4, η_p^2 = 0.04 (see Appendix C).

To summarise, the error difference was lower in the focus attention condition compared to the divided attention condition and overall performance decreased when the set size increased.

Discussion

This study set the aim to analyze the decline of VWM function throughout ageing by comparing two age groups: a young adult group (18-25) and a middle-aged adult group (40-60). It was hypothesised that middle-aged adults would perform worse than young adults in the focus attention condition because the efficiency of filtering out the relevant features diminishes with age which would be in line with the inhibitory-deficit hypothesis.

Furthermore, it was hypothesised that, since it is the case in old adults (60 upwards) the recall preciseness dropped in earlier studies when the number of stimuli rose (e.g. Ma et al., 2014), the same would happen for the middle-aged adults when compared to the young adults' group in this study. This effect was hypothesised to be especially visible in the divided attention condition which would be in line with the LR model while no visible effect for the divided attention condition would be deemed inconclusive between DC and LR model.

The influence of age

First of all, the middle-aged adult group was better than the young adult group in discriminating the features during the pre-experimental part in both, the colour and orientation condition. This is counterintuitive at first since it would be commonly expected that visual perception should decline with age. However, the differences were not significant and hence the study of Faubert (2002) can give explanation. In this study, earlier research was reviewed about perceptual processing of visual stimuli, and found that while for complex stimuli, age related decline sets in with regard to perceptual processing, this is not the case for simple stimuli (Faubert, 2002) like the ones used for this study. Therefore, it is not necessary to explore this result further.

For the experimental part, results showed that age did not have a significant effect on VWM function. Although it was hypothesised that young adults would have a higher-recall preciseness than middle-aged adults, it was the middle-aged adult group which demonstrated better memory scores. Nevertheless, as predicted by the inhibitory-deficit hypothesis, young adults scored better in the focused attention condition in comparison with the middle-aged adults, leading to inconclusive results about whether the inhibitory-deficit hypothesis should be accepted or not. On the one hand, middle-aged participants might have had difficulties in focusing on one particular feature during the focused attention condition while in the divided attention condition this effect resolved since they were allowed to focus on both which would be perfectly in line with the inhibitory-deficit hypothesis. On the other hand, despite multiple studies having examined that recall preciseness declines throughout the ageing process (Chen et al., 2003; Jost et al., 2011) this was not the case in this study.

Additionally, that age did not significantly affect recall preciseness, is not in line with the study of Illiadis & Van der Lubbe (2020) who despite not finding an individual effect of age, found significant interaction effects of it with attention condition and set size. This study however, only found an insignificant but important effect of age on attention condition. It is advised that more experiments should be done in the future that have the potential to give more insight into the inhibitory-deficit hypothesis.

Visual working memory function

In order to explain VWM function, and hence to be able to pin down the effect of age in the light of the inhibitory-deficit hypothesis on VWM in the best way, the above-mentioned results will be evaluated further in the light of the LR and the DC model.

First of all, young adults compared to middle-aged adults and participants in general, were better in the focused attention condition than in the divided attention condition indicating that the focus on two features in the divided attention condition stressed the multitude of storages, each focusing on different features (e.g. one on colour, one on orientation) and each having demands for attention resources, much more than in the focused attention condition. This result is in line with the LR model and the research of Markov et al. (2019) and Wang et al. (2017) who both independently manipulated the memorised set size for features from two separable dimensions (colour and orientation), as it was done in this study, and found that VWM capacity for a given feature depended on the set size in the corresponding dimension rather than joint set size in both dimensions. Therefore, the better score of young-adults than middle-aged adults and the better score of participants in general in the focused attention condition in comparison with the divided attention condition is best explained by the inhibitory-deficit hypothesis and the LR model.

With regard to set size and the effect on recall preciseness for different age groups and hence the second hypothesis of this study, the middle-aged adult`s results were better in comparison to the young adults for all the different variations in set size. This leads to a rejection of the second hypothesis and an inconclusive result whether the LR model or the DC model explains VWM function better in the circumstances of the second hypothesis. Nevertheless, it is of importance to not only view the DC and LR model in light of the effects of set size and age on recall preciseness but also on the sole effect of set size on the recall preciseness of all the participants regardless of age group in order to find clues on which model is better outside the field of ageing and thus should be preferred in the future for more general usage.

With regard to that, set size affected recall precision significantly. The more the set size increased in this study, the more the recall preciseness decreased. This result verifies the other assumption of the LR model, that the more features, in general, have to be encoded, the lower recall preciseness will be (Schneegans & Bays, 2019; Van den Berg et al., 2019). However, this finding can also be interpreted in the theoretical underpinnings of the DC model since a relatively sharp drop in recall preciseness was detected from set size 1 to set size 3, indicating that no slots were available anymore to encode the stimuli accurately. This would match with the research of Souza (2016) who found the same drop in preciseness. Which model to prefer in this regard is inconclusive but what certainly can be interpreted instead, same as Van der Lubbe et al. (2019) did, is that the limit of the VWM is reached before the set size of four items. Additionally, this explains why there was no significant difference anymore between the set size of three and the set size of four.

Lastly, the interaction effect of set size and attention condition would have tipped the scale again in favour of the LR model. This is because participants repeatedly scored better in the focus attention condition for all set sizes compared to the divided attention condition for all set sizes, indicating the same conclusion as described above, that VWM capacity for a given feature depended on the set size in the corresponding dimension rather than joint set size in both dimensions (Markov et al., 2019). However, because the covariate analysis did not find such interaction if age was accounted for as a covariate, the results remain inconclusive regarding the interpretation of this effect in the context of the DC and LR models.

Study limitations and suggestions for future directions

Length of the study

The study conducted took approximately slightly less than two hours. For a working memory task, this is a very long time since concentration has to be consistently at high levels. A lot of participants uttered later on that the task was straining. Therefore, the risk of not adequately portraying a normal VWM function of the participants might arise, giving room for guessing behaviour if concentration deteriorates. For future studies, it is advisable to find a better balance between the number of trials and sound results.

Sample

Although the sample size was already increased by 133% compared to the study of Illadis & Van der Lubbe (2020) (from 18 to 24), this study still featured a relatively small sample size. Especially since most of the results were not replicated from the stated study, a larger sample size is important to gain more reliable information about effects at the population level. Additionally, the young adult group mostly consisted of university students, while the middle-aged adult group mostly consisted of middle-class parents. For future studies, a more varied sample should be used to reflect the population more accurately, preferably assembled with random sampling instead of convenience sampling.

Future research

Specifically with regard to this study, future research should take individual differences into account as stated above. Additionally, to get a better grasp of what happens during the tasks, the usage of EEG measurements might be of help to see potential differences between age groups. No effect of age was found in this study. On the contrary, the study of Illadis & Van der Lubbe (2020) found an effect. Therefore, a third study should be conducted to give more matter to the research. For this study, as already advised by Illadis & Van der Lubbe (2020), a third age group, the old-adult group (60 rising), could be consulted to get more insight into the transitions from young adult to middle-aged adult to old adult. Lastly, it is not advisable to opt for a set size above four stimuli, despite being advocated by Souza (2016), since the limit of this sample was hit at three stimuli already.

Conclusion

The results of the present study revealed that there was no significant effect of age on VWM function, contrary to what was predicted by the inhibitory-deficit hypothesis. However, young adults scored better in the focused attention condition than middle-aged adults which is in line with the inhibitory-deficit hypothesis. In other words, if VWM function did not decline in middle-aged adults because of filtering abilities is inconclusive. On the other hand, effects of set size and attention condition were found, indicating a slightly better explanation of the LR model over the DC model for the data in this study because of the existence of feature independent memory stores. Participants were best at memorizing stimuli from the focused attention condition with one stimulus and worst in the divided attention condition with four stimuli. Furthermore, there was no difference between the three stimuli condition and the four stimuli conditions, showing that the limit of the VWM is reached before the set size of four items.

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Appendix A

Informed Consent Form German

Das Ziel dieser Studie ist die Investigation der Entwicklung des Kurzzeitgedächtnisses in verschieden Altersgruppen (18-25, 40-60). In Verbindung damit, wirst du in dieser Studie erst ein paar demographische Fragen beantworten, danach einen Farbenblindnesstest machen, gefolgt von einer Aufgabe in der verschiedene Stimuli unterschieden werden müssen, gefolgt von mehreren Aufgaben über dein Kurzzeitgedächtnis. Das Experiment wird ungefähr 2 Stunden dauern. Die Daten werden nur für meinen Report genutzt, und werden mit niemandem geteilt oder für einen anderen Zweck als diese Bachelor These benutzt. Die Daten deines Experiments werden spätestens am 30 Mai 2023 gelöscht, genauso wie die Informationen über Nationalität, Alter, und Geschlecht.

Ich habe die Informationen zu dieser Studie gelesen und sie verstanden oder ich habe sie vorgelesen bekommen. Ich hatte die Möglichkeit Fragen zu stellen und sie wurden mir zu meiner Zufriedenheit beantwortet.

- Ja
- Nein

Ich stimme zu freiwillig Teilnehmer dieser Studie zu sein und verstehe dass ich jederzeit verweigern kann Antworten zu geben und dass ich jederzeit von dieser Studie zurückziehen kann ohne einen Grund anzugeben.

- Ja
- Nein

Ich verstehe, dass die Teilnahme an dieser Studie beinhaltet Aufgaben zum Thema Kurzzeitgedächtnis zu machen und demographische Fragen zu beantworten, die für die Analyse dieser Studie benutzt werden und für die nächsten 12 Monate gespeichert werden.

- Ja
- Nein

Ich verstehe, dass meine Informationen die über mich gesammelt wurden mit niemandem geteilt werden, über den Forscher dieser Studie und seine Supervisor hinaus

- Ja
- Nein

Unterschrift Teilnehmer:

Kontaktdaten für mehr Informationen:

Name: Noah Plotz n.plotz@student.utwente.nl

Kontaktdaten:

Für Fragen über deine Rechte als Studienteilnehmer bitte wende dich an das Ethik Komitee der Geistes & Sozialwissenschaften der Fakultäten Verhaltens, Management und Sozialwissenschaften der University of Twente: ethicscommittee-hss@utwente.nl

Jetzt würde ich dir gerne ein paar demographische Fragen stellen.

Wie alt bist du?

Was ist dein Geschlecht?

- Mann
- Frau
- Nicht binär/ drittes Geschlecht
- Ich ziehe vor keine Antwort zu geben
- Anderes

Was ist deine Nationalität?

Informed Consent Form English

The purpose of this research study is to investigate the development of short-term memory in different age groups (18-25, 40-60). With regard to this, in this research you will first have to do a colour blindness test, followed by a differentiation task of different stimuli, and ended by multiple tasks about your short-term memory. The experiment will take you approximately 2 hours to complete. The data will be used for my report only, and will not be shared or used for any other purpose. Your data from the experiment will be deleted after having analysed it, the latest by the 30 of May 2023, as well as the personal information containing nationality and age.

I have read and understood the study information or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

- Yes
- No

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

- Yes
- No

I understand that taking part in the study involves answering questions related to the topic of short-term memory and demographical questions that will be used to analyse the research conducted and archived for the following 12 months.

- Yes
- No

I understand that the information I provide will be used for quantitative research in the context of a university bachelor thesis.

- Yes
- No

I understand that information collected about me will not be shared beyond the study team and the study teams' tutor.

- Yes
- No

Sign Participant:

Study contact details for further information:

Name: Noah Plotz n.plotz@student.utwente.nl

Contact Information:

For Questions about Your Rights as a Research Participant If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Now I want to ask some demographical information from you.

What is your age?

What is your gender?

- Male
- Female
- Non-binary / third gender
- Prefer not to say
- Other

What is your nationality?

Appendix B

Results of the ANOVA analysis

Tests der Innersubjekteffekte

Maß: MASS_1

Quelle		Typ III Quadratsumme	df	Mittel der Quadrate	F	Sig.	Partielles Eta-Quadrat
SS	Sphärizität angenommen	7,602	2	3,801	132,780	<,001	,858
	Greenhouse-Geisser	7,602	1,661	4,576	132,780	<,001	,858
	Huynh-Feldt (HF)	7,602	1,862	4,083	132,780	<,001	,858
	Untergrenze	7,602	1,000	7,602	132,780	<,001	,858
SS * Age	Sphärizität angenommen	3,750E-5	2	1,875E-5	,001	,999	,000
	Greenhouse-Geisser	3,750E-5	1,661	2,257E-5	,001	,998	,000
	Huynh-Feldt (HF)	3,750E-5	1,862	2,014E-5	,001	,999	,000
	Untergrenze	3,750E-5	1,000	3,750E-5	,001	,980	,000
Fehler(SS)	Sphärizität angenommen	1,260	44	,029			
	Greenhouse-Geisser	1,260	36,551	,034			
	Huynh-Feldt (HF)	1,260	40,968	,031			
	Untergrenze	1,260	22,000	,057			
AC	Sphärizität angenommen	1,822	1	1,822	60,880	<,001	,735
	Greenhouse-Geisser	1,822	1,000	1,822	60,880	<,001	,735
	Huynh-Feldt (HF)	1,822	1,000	1,822	60,880	<,001	,735
	Untergrenze	1,822	1,000	1,822	60,880	<,001	,735
AC * Age	Sphärizität angenommen	,086	1	,086	2,874	,104	,116
	Greenhouse-Geisser	,086	1,000	,086	2,874	,104	,116
	Huynh-Feldt (HF)	,086	1,000	,086	2,874	,104	,116
	Untergrenze	,086	1,000	,086	2,874	,104	,116
Fehler(AC)	Sphärizität angenommen	,659	22	,030			
	Greenhouse-Geisser	,659	22,000	,030			
	Huynh-Feldt (HF)	,659	22,000	,030			
	Untergrenze	,659	22,000	,030			
SS * AC	Sphärizität angenommen	,116	2	,058	4,731	,014	,177
	Greenhouse-Geisser	,116	1,557	,074	4,731	,022	,177
	Huynh-Feldt (HF)	,116	1,730	,067	4,731	,018	,177
	Untergrenze	,116	1,000	,116	4,731	,041	,177
SS * AC * Age	Sphärizität angenommen	,030	2	,015	1,240	,299	,053
	Greenhouse-Geisser	,030	1,557	,019	1,240	,294	,053
	Huynh-Feldt (HF)	,030	1,730	,018	1,240	,296	,053
	Untergrenze	,030	1,000	,030	1,240	,277	,053
Fehler(SS*AC)	Sphärizität angenommen	,538	44	,012			
	Greenhouse-Geisser	,538	34,259	,016			
	Huynh-Feldt (HF)	,538	38,067	,014			
	Untergrenze	,538	22,000	,024			

Appendix C

Results of the ANCOVA analysis

Tests der Innersubjekteffekte

Maß: MASS_1

Quelle		Typ III Quadratsumme	df	Mittel der Quadrate	F	Sig.	Partielles Eta-Quadrat
SS	Sphärizität angenommen	1,008	2	,504	17,633	<,001	,445
	Greenhouse-Geisser	1,008	1,662	,607	17,633	<,001	,445
	Huynh-Feldt (HF)	1,008	1,862	,541	17,633	<,001	,445
	Untergrenze	1,008	1,000	1,008	17,633	<,001	,445
SS * AgeCO	Sphärizität angenommen	,002	2	,001	,037	,964	,002
	Greenhouse-Geisser	,002	1,662	,001	,037	,942	,002
	Huynh-Feldt (HF)	,002	1,862	,001	,037	,956	,002
	Untergrenze	,002	1,000	,002	,037	,849	,002
Fehler(SS)	Sphärizität angenommen	1,258	44	,029			
	Greenhouse-Geisser	1,258	36,556	,034			
	Huynh-Feldt (HF)	1,258	40,974	,031			
	Untergrenze	1,258	22,000	,057			
AC	Sphärizität angenommen	,572	1	,572	18,642	<,001	,459
	Greenhouse-Geisser	,572	1,000	,572	18,642	<,001	,459
	Huynh-Feldt (HF)	,572	1,000	,572	18,642	<,001	,459
	Untergrenze	,572	1,000	,572	18,642	<,001	,459
AC * AgeCO	Sphärizität angenommen	,070	1	,070	2,267	,146	,093
	Greenhouse-Geisser	,070	1,000	,070	2,267	,146	,093
	Huynh-Feldt (HF)	,070	1,000	,070	2,267	,146	,093
	Untergrenze	,070	1,000	,070	2,267	,146	,093
Fehler(AC)	Sphärizität angenommen	,675	22	,031			
	Greenhouse-Geisser	,675	22,000	,031			
	Huynh-Feldt (HF)	,675	22,000	,031			
	Untergrenze	,675	22,000	,031			
SS * AC	Sphärizität angenommen	,070	2	,035	2,803	,071	,113
	Greenhouse-Geisser	,070	1,573	,044	2,803	,086	,113
	Huynh-Feldt (HF)	,070	1,751	,040	2,803	,080	,113
	Untergrenze	,070	1,000	,070	2,803	,108	,113
SS * AC * AgeCO	Sphärizität angenommen	,022	2	,011	,882	,421	,039
	Greenhouse-Geisser	,022	1,573	,014	,882	,400	,039
	Huynh-Feldt (HF)	,022	1,751	,013	,882	,410	,039
	Untergrenze	,022	1,000	,022	,882	,358	,039
Fehler(SS*AC)	Sphärizität angenommen	,546	44	,012			
	Greenhouse-Geisser	,546	34,615	,016			
	Huynh-Feldt (HF)	,546	38,517	,014			
	Untergrenze	,546	22,000	,025			