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The Effects of Ageing on the Organisation of Visual Short-Term Memory

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Abstract:
Past research has reported a deterioration in the corpus callosum of older adults that causes less interhemispheric communication between the hemispheres. However, this study did not measure the corpus callosum; instead, it assumes that older people have smaller corpus callosum based on past research. Past research has also reported a considerable impairment in the elders' capacity to handle global statistics instead of local figures but a global preceding effect in younger adults. To study the ageing effects on the organisation of VSTM, 45 younger adults aged between 18-28 and 44 older adults aged between 62-80 (some exclusions were made later) participated in a change detection task. A memory display was presented to the participants. After a short delay, a test display was presented with one of the four conditions: single probe, whole probe, Half probe (across hemifield) or half probe (within hemifield). Participants had to choose if the colours were similar or distinct between the memory and the test display. Only the colours and probe conditions could change between memory and the test display, but the locations stayed the same. The study builds on the present knowledge of VSTM-related age decline in cognition. It was reported that overall, the older participants performed less accurately on the change detection task than the younger adults. The effects of the answer and the interaction between the probe condition and the answer were also reported. However, there was no significant interaction between the probe condition and the group. It was a complex online study which was a significant limitation of the study. Future research can investigate memory consolidation in older adults using a simpler design in a lab-based study. The present study is a follow-up study for Anonymous (2020).

Keywords: organisation of VSTM, probe conditions, ageing, local configurations, global configurations, hierarchical organisation, corpus callosum, interhemispheric interaction, Change detection task.

1. Introduction: -

1.1 Describing and testing visual short-term memory: -

Visual short-term memory (STM)—the storage of visual stored data for a brief time frame while being denied direct input—decreases with age (Gazzaley et al., 2005). VSTM has relatively low storage space and generates primarily schematic representations reasonably quickly. It is commonly regarded as the more extensive working memory system's optical storage system (Luck, S. J.,2008). VSTM depictions can withstand eye movements, blinks, and other visual disruptions and may help preserve consistency across all these disruptions (Luck, S. J.,2008). However, visual short-term memory (VSTM), a principal constituent of normal cognition, begins to degrade around age 21, with item capacity half by age 75 (Brockmole & Logie,2013). When several objects must be recalled in a few seconds, both the quantity

that may be recalled and the accuracy with which each one is recalled decrease across the lifespan of an adult (Mitchell, D. J., & Cusack, R.,2018).
There are several ways to test VSTM. A sequential comparison process is used in VSTM studies. For instance, the individual could be given a coloured square for 500 milliseconds and afterwards asked to confirm that it has the same colour as the memorised colour after a 1000 millisecond delay (Luck, S. J.,2008). The change-detection task is a frequent variant of the sequential comparison process. Observers examine a short sample array containing one or more items that the observers attempt to recall in the one-shot variant of the change-detection task (initially devised by Phillips, 1974). During the short retention time, the observers examine the test and sample arrays to discover if they detect differences. *(e.g., figure 1)* (Luck, S. J.,2008). In VSTM, individuals can recall four to five phrases or single characteristics (Luck & Vogel, 1997). The Change detection task performance differed considerably between age categories, with younger people recognising changes across two visual arrays more rapidly than older adults (Ebaid, D., & Crewther, S. G.,2019). The Change detection task primarily relies on bottom-up cognition; hence the findings are consistent with previous studies that imply bottom-up computation is much more sensitive to age-related decrease than top-down attention control (Madden et al.,2007). Therefore, the change detection task is the best way to measure the age-related decline in VSTM.

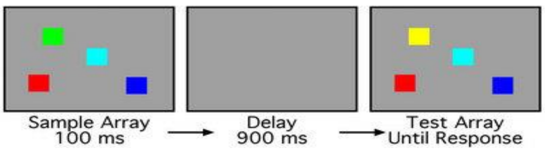

Figure 1: An example one-shot variant of the change-detection task by Luck, S. J. (2008).

In terms of ageing theories, reduced VSTM capacity during ageing is addressed by two main theories. According to one explanation, older individuals are compromised in their capacity to tie various informational fragments into one coherent unit, which is crucial for Visual information acquisition (Naveh-Benjamin, 2006). On the other hand, the second argument contends that older individuals have a diminished capacity for suppressing unnecessary information (Hasher & Zacks, 1988). Colour and location bindings have been challenging to retain in older adults (N. Cowan et al., 2006). Research also suggests that "developmental shifts in VSTM ability are represented not only by changes in the neural reactions of to-be-stored items but also by modifications in the neural responses for to-be-ignored items." (Astle, D. E., & Scerif, G.,2011). Nevertheless, there is a specific storage capacity of VSTM.

1.2 Visual short-term memory storage and probe types: -

Inside the visual modality, the quantity of items that may be acquired and retained at the same point appears to be restricted to roughly four (Irwin, D. E.,1992). It has been discovered that observed objects retain more in VSTM as compared to unattended items (Schmidt et al,.2002). Understanding the causes behind the minimal ability to retain visual representations, which ranges from 3 to 5 significant objects in young adults, differs significantly among individuals, and diminishes in healthy ageing, is an essential focus of VWM studies (Cowan, N.,2010). However, four different probe types are utilised in the present study.

In terms of within and across hemifield probe conditions, Gratton and colleagues (Gratton, Corballis, & Jain, 1997) discovered a recognition benefit for line patterns displayed within a single hemifield during research and testing when tried to compare to shapes displayed in various hemifields, implying a fundamental distinction in embedded information between both the two cerebral hemispheres. Alvarez and Cavanagh (2004) established in healthy individuals utilising an MOT paradigm that when things are divided across the two hemifields, they may be monitored twice as frequently as when all of them are given in the same hemifield. Therefore, specific capacity limits in VSTM for the left and right hemifields should be expected so that twice that many items could be encrypted and retained concurrently when kept separate across the two hemifields instead of presenting them within a single hemifield (Delvenne, J. F.,2005). However, the study's findings by Delvenne, J. F. (2005) reveal that performance was the same within and across hemifields *(figure 2)*, which contradicts the presence of separate VSTM storage resources in the two visual hemifields. However, this study will focus on the performance of older adults in half-probe (within hemifield) and half-probe (across hemifield) conditions. In the present study, the within and across hemifield conditions are studied in terms of the degradation of the corpus callosum in older adults.

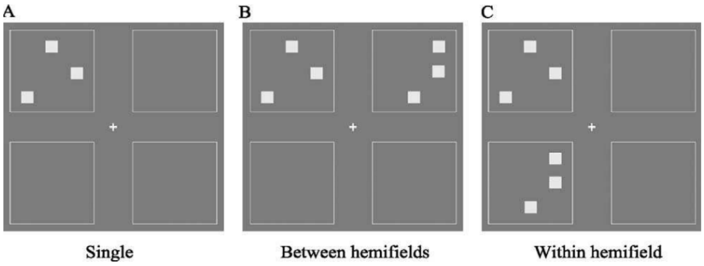

Figure 2- Example of displays (between hemifield and within hemifield) in the study by (Delvenne, J. F.,2005)

However, the two other types of probes are single probes and whole probe conditions *(figure 3)*. A test display is shown following the study and a short retention interval. One target is shown at a specified position in the single-probed recognition paradigm. Its objective might be either the previously examined object or a different item (Rouder et al., 2011). A whole collection of objects is displayed at the test for whole-display recognition. This combination is either identical to the original examined set or one piece is unique (Rouder et al., 2011).

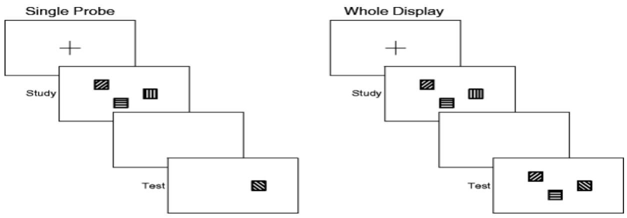

Figure 3- example of single and whole probe condition (Rouder et al., 2011)

In terms of the context in the displays, Gazzaley et al. (2005) argued that the context might provide less advantage to elderly folks. Poor attentional filtering has indeed been demonstrated to impair memory performance in older individuals by causing unrelated data to go through more intensely and compete for recollection (Gazzaley et al., 2005). Research shows that younger adults generate multiple-item representations for colour retention (Brady, T. F., & Alvarez, G. A.,2011). Additionally, they discovered that constant context increases all memory metrics, particularly accuracy. Furthermore, according to a study conducted among young adults (Rajsic & Wilson, 2014), when the identical context was provided across the sample and probe, subjects were more inclined to report the correct item, yet without more precision. Therefore, the evidence suggests that younger adults use context to aid memory recollections.

1.3 The Local and global processing: -

Hierarchical forms (Navon, 1977) in which big (global) shapes were built from smaller (local) ones have proven helpful in investigations of perceptual organisation and cerebral specialisation in both healthy subjects and a broad array of psychiatric disorders. Substantial attention and investigation have been created by David Navon's (1977) well-known result dubbed "global precedence." Representations on the global object level impact the recognition of local-level components within a hierarchical input arrangement of VSTM (Navon,1977). Therefore, according to the hierarchical organisation of VSTM, the local components are processed after processing global objects. Employing compound letters, giant letters formed from tiny letters, research showed that participants could recognise the large letter without interruption from the identity of the smaller letters (Nie, Q. Y., Müller, H. J., & Conci, M.,2017). In comparison, the detection of the smaller letters could have been better due to the identification of the giant letter, which also supports the hierarchical trend in VSTM. Even though several investigations conducted since then on young healthy people have verified this impact (Lamb & Yund, 2000). However, several researchers (e.g., Oken et al., 1999) have lately proposed that the global processing benefit may diminish or even reverse once people reach the age of 65. Therefore, it suggests some disturbances in the organisation of VSTM during ageing. Similarly, Lux et al. (2008) investigated how healthy young or old humans perceive sequential visual stimuli. Their findings support prior research on local precedence in healthy-aged people. Over 60% of the elderly group had a local advantage, whereas just 4% had a global processing benefit (Lux et al.,2008).

Similarly, according to the study's findings conducted by Barry S. Oken, MD, Shirley S. Kishiyama, et. al. (1999), older people comprehend global pictures more rapidly when displayed in the left visual field and local stimuli more rapidly when shown in the right visual field. Nevertheless, irrespective of the fact that there was no overall difference between global and local processing ability amongst the young, there was a considerable impairment in the elders' capacity to handle global statistics as opposed to local figures (Barry S. Oken, MD, Shirley S. Kishiyama, et al.,1999). Irrespective of the field of vision in which the visuals are displayed, older participants need help digesting global than local elements. The decline in the ability to process global information may be connected to the decreased attentional field seen in other age-related cognition losses such as visual search (Barry S. Oken, MD, Shirley S. Kishiyama, et al.,1999).

However, there are some contrasting findings too. Findings of the study by Roux and Ceccaldi (2001) discovered that global processing was more evident in older individuals than in younger ones, implying that elderly individuals had a lower capacity for blocking prominent global visual data. Similarly, Gottlob and Madden (1999) asserted that elderly persons could only process sequentially, first on a global basis, then on a local one, but younger people can comprehend both simultaneously. Nevertheless, the overall strength of data from most previous studies suggests a probable tilt away from global precedence during old age (Insch et al.,2012). Therefore, the evidence suggests that older adults benefit less from the context of global information and tend to attend more to the local information than the global context. There is a need for more research in the local and global visual processing in healthy older adults using the change detection task, which this study aims to do through testing responses of older adults on single (local) and whole probe (global) conditions. Prior research has also indicated that ageing diminishes hemisphere lateralisation utilising Navon's (1977) global-local hierarchical stimulus paradigm (Cabeza et al., 2002). This decrease in hemisphere lateralisation has also been linked to the degeneration of the corpus callosum (Müller-Oehring et al., 2007).

1.4 Corpus callosum and VSTM: -

The corpus callosum comprises at least 200,000,000 axonal fibres, interconnecting homologous parts of the left and right hemispheres in a topographical pattern (Aboitiz, Ide, and Olivares, 2003). According to psychophysiological experts, VSTM impacts are frequently most substantial in the hemisphere opposite to the hemifield toward which attention is focused (Heinze, Luck, Mangun, & Hillyard, 1990). Therefore, VSTM is contralaterally organised (Delvenne, J. F.,2005). The contralateral organisation would require interhemispheric interaction to exchange information. Additionally, there is no final theory for global and local interference processes, but new investigations have offered corroborating evidence that interhemispheric interaction through the corpus callosum impacts interference. Interhemispheric interactions may be a plausible neurological explanation for stimulation and interference between global and local processing (Forster & Corballis, 2000). Split-brain research reveals that the corpus callosum regulates local-global interference (Robertson et al., 1993). Furthermore, researchers have discovered that callosal size decreases with ageing (Doraiswamy et al., 1991). Additionally, following the corpus callosum deficit theory (Goldstein & Braun, 1974), age-related decreases in the size of the corpus callosum *(e.g., figure 4)* result in less effective information transfer between hemispheres. According to Gootjes, L., Van Strien, J. W., and Bouma (2004), age-related increasing asymmetry is caused by a loss in corpus callosum efficiency, which results in decreased interhemispheric communication. Similarly, Driesen, N. R., & Raz, N. (1995) argued that younger participants exhibit more significant corpus callosum regions than older adults, suggesting that the corpus callosum declines with age.

In addition, Witelson (1989) discovered that the corpus callosum's broad area and the isthmus's size decrease as one ages. Others have discovered a decline in corpus callosum size and area with ageing (Byne et al., 1988). The corpus callosum is said to decrease with age and reduction in corpus callosum length (Byne et al., 1988) and its area (Allen et al., 1991). Evidence also shows that interhemispheric connectivity is damaged in aged people (Bellis & Wilber, 2001). However, studies must be conducted to ascertain whether this impacts cognitive performance. Therefore, this study is essential to examine how ageing affects the organisation of VSTM within and between the cerebral hemispheres. Reuter-Lorenz and Stanczak (2000) proposed that the ageing process significantly affects different capacities of the corpus callosum. However, some other pieces of the literature suggest otherwise as well. Suganthy et al. (2003) reported considerable growth in the length of the corpus callosum with increasing age, both in males and females, which was a novel discovery in the current investigation. Nevertheless, most literature still points towards corpus callosum degrading with age and becoming smaller, interfering with interhemispheric communication.

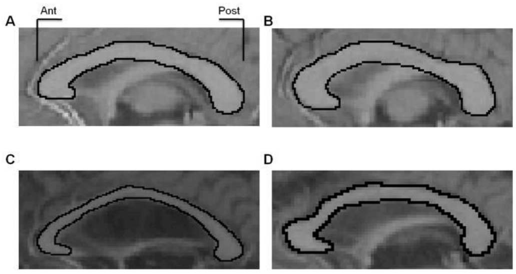

Figure 4: Two sample instances of the corpus callosum from young adult participants (A, B) and two older adult individuals (C, D). These photos are used to indicate age variations in callosal size. (Fling et. al., 2011).

However, this study did not measure the size of the corpus callosum. Based on previous findings, older adults have difficulty assimilating information because there is less interhemispheric contact between the two hemispheres. So, older adults are predicted to perform better in half probe (within hemifield) condition than half probe (across hemifield) condition in this study since they perceive information from both hemispheres independently. A recent study by Chen Wt. al. (2019) discovered that many networks exhibited reduced inter-hemispheric connectivity with age. Additionally, the findings by Moscufo et al. (2011) show that ageing causes inadequate integration of inter-hemispheric visuospatial information. Lastly, Sullivan and colleagues (2001) reported that age-related corpus callosum decreases were linked with decreased interhemispheric communication effectiveness. Therefore, aged people have difficulty integrating information because of relatively less interhemispheric communication between both hemispheres. They might perceive information from both hemispheres separately. More research that offers insights into cognition and brain ageing is required (Phillips et al., 2019).

1.5 Aims and Hypothesis: -

Prior research has indicated that the corpus callosum, the brain region that connects the two cerebral hemispheres, is smaller in older people. Nevertheless, to our knowledge, no current study is underway to determine if this affects cognitive functioning. Additionally, prior studies point towards older adults' inability to process global information. Therefore, this study aims to look at the ageing effects on the organisation of VSTM within and across the hemispheres of the brain and also at the effects of local/global processing in older adults on the change detection task. VSTM is carefully examined using change detection, which entails swiftly displaying a sample presentation of items for memorising that stops for a maintenance time of a second or more, followed by a test display (Mitchell, D. J., & Cusack, R.,2018). The participants were asked to look at a memory display, and then a test display was presented with any one of four different types of probes (whole probe, half probe (within hemifield), half probe (across hemifield), and single probe). They had to decide whether there was a change in colour between the memory display and the test display.

There are four main hypotheses in the study. Firstly, since the past research by Oken et al. (1999) observed a considerable impairment in the elders' capacity to handle global statistics as opposed to local figures. Similarly, Marshall et al. (2008) reported local precedence effects in typical older participants. Therefore, it is hypothesised that older adults would perform more accurately in the single probe (only a target square is present/ local) condition compared to the whole probe condition because older adults will not take benefit of context present in the whole probe (global) condition. Secondly, past research

(Brockmole & Logie,2013) pointed out overall VSTM declines with age; therefore, it was hypothesised that older adults would perform less accurately across all four conditions than younger adults.
Thirdly, past research by Gootjes et. al, (2004) reported that deterioration in corpus callosum function leads to diminished interhemispheric interaction. Therefore, older adults process information independently. Considering that, it is hypothesised that older adults will perform better in half probe (within hemifield) condition than half probe (across hemifield) condition. This is because the stimuli are only presented on one side of the hemifield in half probe (within hemifield) condition, so it will be convenient for older adults to process it independently. Lastly, past research by Jiang and colleagues (Jiang Y., Olson, I. R., & Chun, M. M. ,2000) discovered that global configurations aid in the memory of individual colours for younger adults. According to a study conducted on young people, global cues increase efficiency, indicating that it is a helpful information resource for remembering. Therefore, it was hypothesised that younger adults would perform more accurately in the whole probe condition than the single probe condition because they benefit from the context.

2. Methods: -

2.1 Participants: -

A total of eighty-nine participants were recruited through opportunity sampling. There were forty-five younger adults between the age of 18 to 28 with a mean age of 20.2 (*SD*=1.83). There were 38 females, 6 males and one other within the sample of younger adults. Regarding handedness, five were left-handed, thirty-seven were right-handed, and three were ambidextrous individuals. The participant pool was used to recruit younger adults, and they were offered five credits for participating in the study.
Forty-four older adults aged 62-80 with a mean age of 69.3 (*SD*=3.57). There were 23 females and 21 males in the sample of older adults. In terms of handedness, one was left-handed, and forty-three were right-handed individuals. An online participant recruitment platform named Prolific was used to recruit older adults, and they were awarded £4.50 for their participation in the study.
Some pre-exclusions were carried out before the study. People with visual impairments or health diseases influencing neurological functioning (e.g., some cognitive challenges) refrained from participating in this study because of the nature of the topic. Participants should have normal or correct eyesight to take part in the study. Participants must have binocular vision to participate in this study since both visual fields must be included. Participants are additionally eliminated if they are colour-blind, as this may substantially impair their ability to detect whether the colour combinations given are identical or distinct from earlier stimuli.
A few post-exclusions were also carried out before running the analysis. The exclusions were made based on MoCa scores (MoCa scores below 10 were excluded), age-related reasons (age criterion for older adults was 65-80 and 18-30 years for younger adults), any response bias (i.e., 2 *SD* below or above the mean), handedness (left-handed and ambidextrous individuals were excluded). Cerebral structural and functional asymmetries are less prominent in left-handed individuals than in right-handers (LeMay, M.,1992). Therefore, left-handed and ambidextrous individuals were excluded to maintain a consistent sample. Overall, those were the post-exclusion criteria carried out after the experiment.
The University of Leeds (Faculty of Medicine and Health, School of Psychology) Research Ethics Committee authorised this study (Reference: PSYC-708 Date of Approval 19/12/22). The exact nature of the study was revealed to the subjects. All effects were made to minimise biased results.

2.2 Design: -

A 2 x 2 x 4 mixed experimental design was utilised. There were two independent variables, the age groups (younger adults vs older adults) and the four probe conditions (whole probe, half probe (within-hemifield), half probe (across-hemifield) and single probe). The dependent variables were reaction time and accuracy (% of correct responses). The two within-subject factors were the four probe conditions (whole probe, single probe, half probe (within hemifield) and half probe (across hemifield)) and answers responses (yes or no), and the between-subject factor was the age group (older adults vs younger adults). The research was quantitative, with data collected by utilising experimental procedures.

In the memory display, the squares of eight distinct colours were randomly placed in the following order in each quadrant: two colours on the bottom left, two colours on the bottom right, two colours on the top left, and two colours on the top right. Therefore, they were placed so that two distinct colours existed in each quadrant. Although colours could repeat in distinct quadrants, they could not repeat in the same one. Hence, colours could be set in 4 possible locations in each quadrant *(refer to Figure 5)*. For the test display, squares were arranged in the appropriate areas based on the conditions: whole probe, half probe across hemifield, half probe within hemifield and single probe.

Figure 5- Demonstrates the four possible locations in each quadrant.

In terms of the four conditions for the test display, the whole probe condition is where all the eight squares presented in the memory trial were presented in the test trial. In the half probe (across hemifield) condition, the squares (4 squares as two squares in separate quadrants) were presented on both sides of the hemifield in the test display. In the half probe (within hemifield) condition, the coloured squares (4 squares as two squares in each quadrant) were presented only within one side of the hemifield in the test display, even though all eight squares were presented in the memory display. However, a single target square was shown in the test display for the single probe condition. The only changes that occurred from the memory display to the test display were the probe conditions (whole probe, half probe (within-hemifield), half probe (across-hemifield) and single probe) and the colours of the squares. Apart from that, the location of the squares remained the same as the memory display *(refer to Figure 6)*.

Frequent intervals were offered to decrease participants' fatigue, and participants will be permitted to recuperate for as long as they choose. The participants were given a break after every block of the experiment. Each probe condition had six trials in every block; therefore, 6 trials x 4 conditions (whole probe, half probe (within-hemifield), half probe (across-hemifield) and single probe) = 24 trials (i.e., one block). Participants were given breaks after every 24 trials. The experiment had eight blocks and 24 trials in each block; therefore, 24 x 8= 192 trials.

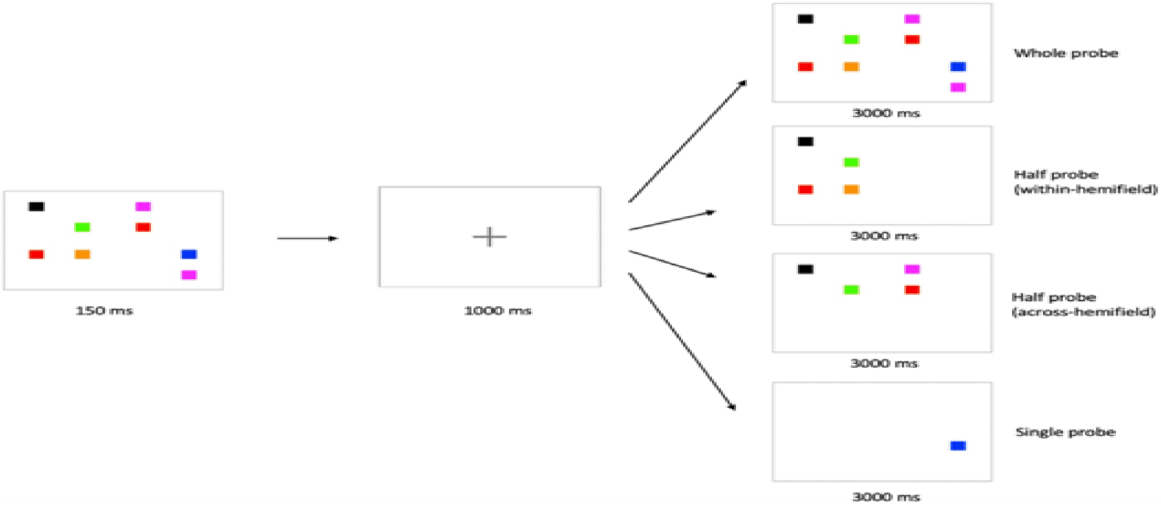

Figure 6- An example of trials in different conditions (4 types of probes)

2.3 Stimuli: -

Eight distinct coloured squares were presented as stimuli. These eight colours were turquoise, yellow, pink, red, black, green, blue and orange *(Appendix A)*. These colours were presented on a white background, and all the colours were very distinct from each other to avoid grouping.

2.4 Materials: -

The subjects participated in a Gorilla-programmed online experiment (gorilla. sc). The size of the squares was 40 x 40 pixels. However, since it was an online experiment, the size of the squares differed according to the screen size of the participants' devices. If the middle of the screen is 50%, then the location of the stimuli was 25% and 40% for the left and top stimuli. At the same time, 75% and 60% were for the right stimuli and bottom stimuli.

The instructions were provided to the participants, and they were required to press the space bar whenever they were ready to start the experiment. Straight after, a blank screen was presented for 1000 ms (one second). After which, a fixation cross was presented for 500 ms. The fixation cross disappeared when a delay of 500 ms was presented. Following that, a memory display was presented for 150 ms. After that, a 1000 ms (one second) retention period was presented, and the retention period aimed to give participants enough time to make a correct evaluation. Finally, a test display is presented for 3000 ms, which gives the participants sufficient time to decide whether the colour in the test display is similar to or distinct from the memory display. The participants had to press 'k' if the squares presented in the test display on that location were the same as the memory display ('yes' answer/ no change between memory display and test display) and 'd' if the squares were different from the one presented in the memory display ('no' answer/ change between memory and test display). The data was not collected if the participant did not respond during the test display of 3000 ms (3 seconds). There was a break after every 24 trials for as long as the participant wanted to take. They could press the space bar to resume the task.

2.5 Measures: -

Participants were asked to answer a few questionnaires before the start of the experiment to test their ability to participate.

1. **Edinburgh handedness questionnaire-** In the social sciences, handedness—the propensity to use one hand more frequently than the other—is typically examined via a questionnaire (Veale, J. F.,2014). The Edinburgh Handedness Inventory (Oldfield, 1971) is a straightforward and condensed 10-item measure that may be utilised in both experimental and clinical work in neuropsychology and other fields (Veale, J. F.,2014). The questionnaire was used to study the hand preference of participants, and left-handed participants were later excluded from the data.
2. **Language and Social background questionnaire-** Three components comprise the Language and Social Background Questionnaire (Anderson et al., 2018). Social Background is the very first section that collects data on demographics. The participant's capacity to comprehend and speak other languages is evaluated in the second section, "Language Background." Community Language Usage Behavior, the third component, discusses language utilisation in various phases of life (Anderson et al., 2018). This questionnaire was used to study the participants' accuracy in English as the study required the participant to be good at English.
3. **Montreal Cognitive Assessment test (MoCA) test-** To identify Mild Cognitive Impairment, the Montreal Cognitive Assessment (MoCA) was created as a quick screening method to identify deficits in cognition (Julayanont, P., & Nasreddine, Z. S.,2017). The administration of this instrument takes around ten minutes. The MoCA tests several aspects of cognition, including abstraction, computation, executive functions, and remembering (Julayanont, P., & Nasreddine, Z. S.,2017). Participants were required to complete the online version of MoCa, which shows their fundamental intellectual capacity and certifies their suitability for study participation.

2.6 Procedure: -

Participants had to complete the experiment online on their own devices in their own time. Participants were provided with the information sheet to read *(Appendix B)* and a consent form to provide their consent *(Appendix C)*. Participants were told they could withdraw before or during the study, and all data acquired throughout their involvement would be deleted. Additionally, distinct participant IDs helped to maintain the anonymity of the participants. Furthermore, a few questionnaires were presented. Participants were instructed to complete the Edinburgh handedness questionnaire *(Appendix E)* to determine their hand preference. A language and social background questionnaire (Anderson, Mak, Keyvani, Chahi & Bialystok, 2018) *(Appendix F)* was provided because participants should all have a good command of the English language. Lastly, Participants were required to take the Montreal Cognitive Assessment (MoCA) test, verifying their ability to participate in the study.

After the consent was provided, the instructions were displayed *(Appendix G)*. Participants were instructed to press the space bar to start the experiment. Eight practice trials were provided. The participants were told to guess the answer if unsure of the response. Participants could take a break after every 24 trials and were provided with feedback on their performance. Participants were also informed that the task was difficult, so they did not stress about low scores. It almost took participants 45 minutes to complete the experiment, and older adults received £4.50 for participation, whereas younger adults received 5 credits through the participant pool. Lastly, the participants were given the debrief sheet *(Appendix D)* containing the study's aim and the researcher's contacts. Additionally, confidentiality was strictly maintained after data collection.

3. Results:

3.1- Exclusions: -

Some exclusions were made after data collection. 12 younger adults were removed from the overall data set. 9 were excluded due to handedness (left-handed), one participant was excluded because of a low MoCa score (below 10), one was excluded because of response bias, and the last one was excluded because of low scores (scores consistently 2 *SD*s below the mean). Therefore, the final data set of younger adults had 33 younger adults aged between 18-28 with a mean age of 20.18 (*SD*=1.86). The final data set of younger adults included five males and 28 females, all right-handed.

Additionally, 8 older adults were removed. 4 were removed because of response bias, two were excluded because of low MoCa score (below 10), one participant was excluded because of age-related reasons (62-year-old) and the last one was removed because of handedness (left-handed). Therefore, the final sample of the older adults comprised 36 people aged between 65-80 with a mean age of 69.30 (*SD*=3.57). After exclusions, there were 21 females and 15 males in the data set of older adults, all right-handed. Therefore, the final data set comprised 69 individuals, 36 older adults and 33 younger adults.

3.2- % of correct responses across all four conditions: -

The means and standard deviations of % of correct responses for the change detection task for all four probe conditions in younger and older adults are shown in Table 1.

Table 1: The means and standard deviation of % of correct responses for all four conditions in younger and older adults

	Half Across Mean *(SD)*	Half Within Mean *(SD)*	Single probe Mean *(SD)*	Whole probe *Mean (SD)*
Younger adults	54.96% (0.06)	60.87% (0.06)	64.60% (0.07)	62.13% (0.07)
Older adults	50.24% (0.06)	57.52% (0.06)	59.50% (0.06)	58.09% (0.06)

3.3 Main effects and interactions:

Additionally, a 2x2x4 mixed ANOVA was conducted with the age group (young adults and old adults) as the between subjects' variable and two within subjects variables, which were the four probe conditions (single probe, whole prove, half probe (across hemifield) and half probe (within hemifield)) and answer (yes and no). There was a significant effect of condition, F (3,201) = 30.58, p <.001, η_p^2=.313. In terms of accuracy, no significant difference (p=.154) between the single probe condition (*M*= .62, *SD*=.06) and the whole probe condition (*M*=.60, *SD*=.07) was found. Additionally, there was also no significant difference (p=1) between the whole probe condition (*M*=.60, *SD*=.07) and the half probe (within hemifield) condition (*M*=.59, *SD*=.06) in terms of accuracy. Participants significantly (p<.001) performed more accurately in the half probe (within hemifield) (*M*=.59, *SD*=.06) condition as compared to the half probe (across hemifield) condition (*M*=.52, *SD*=.06). Furthermore, there were few more significant differences. Participants significantly (p<.001) were more accurate in the single probe (*M*=.62, *SD*=.06) than their performance on the half probe (across hemifield) condition (*M*=.52, *SD*=.06). Participants significantly (p<.001) performed more accurately in the whole probe condition (*M*=.60, *SD*=.07) than their performance on half probe (across hemifield) condition (*M*= .52, *SD*=.06).

Lastly, Participants significantly (*p*=.029) performed more accurately in the single probe condition (*M*=.62, *SD*=.06) than their performance on half probe (within hemifield) condition (*M*=.59, *SD*=.06). Therefore, participants performed most accurately in the single probe condition (*M*= .62, *SD*=.06) and least accurately in the half probe (across hemifield) condition (*M*=.52, *SD*=.06).
Additionally, a significant effect of answer F (1,67) = 23.23, p<.001, η_p^2=.258 was also found in a way that participants across both groups gave more accurate yes responses (*M*=.65, *SD*=.12) than no responses (*M*=.52, *SD*=.11). Furthermore, there was a significant effect of group (young adults and old adults) F (1,67) = 20.27, p <.001, η_p^2=.23 where overall younger adults (*M*=.60, *SD*=.04) performed better as compared to the older adults (*M*=.56, *SD*=.04). Additionally, a significant interaction between condition and answer F (2.7,184) = 174.70, p <.001, η_p^2=.723 was found. However, no significant interaction between the condition and the group was found.

3.4 Further analysis of the interaction between condition and answer: -

This interaction signifies two possibilities. Either there is an effect of the answer on the condition or the effect of the condition on the answer. Therefore, firstly difference between yes and no was tested for each condition using paired samples t-test. For the half probe (within hemifield) condition, there was no significant difference t (68) = -1.31, p=.193 between yes (*M*=.61, *SD*=.17) and no (*M*=.56, *SD*=.17). There was a significant difference t (68) = -5.76, p<.001 between the answer responses for the half probe (across hemifield) condition with yes response (*M*=.63, *SD*=.17) being more accurate than no response (*M*=.41, *SD*=.17). Additionally, there was a significant difference t (68) =7.99, p<.001 in the answer response for the single probe condition such that no response (*M*=.76, *SD*=.14) was more accurate than the yes response (*M*= .48, *SD*=.18). Lastly, there was a significant difference t (68) = -20.06, p<.001 in the answers for the whole probe condition with yes response (*M*=.86, *SD*=.12) being more accurate than no response (*M*=.33, *SD*=.14).
A repeated measures ANOVA was utilised to investigate the effect of condition on answers, therefore, comparing the four conditions for the answer (yes and no) separately using the repeated measures ANOVA. The within-subjects factor was the four conditions (only no answer/ change between memory display and test display). There was a significant difference of condition for the 'no' answer in all the pair of conditions F (3,201) = 154.28, p<.001, η_p^2=.697. The test revealed that the participants were significantly (p<.001) better in the single probe condition (*M*=.76, *SD*=.14) than in the half probe (within hemifield) condition (*M*=.56, *SD*=.17) for the 'no' answer. Additionally, participants were significantly (p<.001) better in the half probe (within hemifield) condition (*M*=.56, *SD*=.17) as compared to the half probe (across hemifield) condition (*M*=.41, *SD*=.17) for the 'no' answer. Participants significantly (p=.007) performed better in the 'no' answer for half probe (across hemifield) condition (*M*=.41, *SD*=.17) as compared to the whole probe condition (*M*=.33, *SD*=.14). Furthermore, there were a few more significant differences. Participants were significantly (p<.001) more accurate in the 'no' responses for the single probe condition (*M*=.76, *SD*=.14) as compared to the half probe (across hemifield) condition (*M*=.41, *SD*=.17) and the whole probe condition (*M*=.33, *SD*=.14). Lastly, the participants performed significantly (p<.001) better in the half probe (within hemifield) condition (*M*=.56, *SD*=.17) as compared to the whole probe condition (*M*=.33, *SD*=.14) for the 'no' response. Overall, participants performed most accurately in the no response/change between memory display and test display for the single probe condition (*M*=.76, *SD*=.14).

Lastly, repeated measures ANOVA was conducted for the yes response in all four probe conditions. The within-subjects factor was the four conditions (yes answer/ no change between memory display and test display). Significant differences in the 'yes' response across the four conditions F (2.8,190) = 120.55, $p<.001$, $\eta_p^2=.643$. The results reported that the participants performed significantly ($p<.001$) better in the 'yes' response of the whole probe condition ($M=.87$, $SD=.12$) compared to the 'yes' response in the half probe (across hemifield) condition ($M=.63$, $SD=.17$). There were no significant differences ($p=1$) between the half probe (across hemifield) ($M=.63$, $SD=.17$) and half probe (within hemifield) condition ($M=.61$, $SD=.17$) for the accuracy in the 'yes' response. Lastly, participants were significantly ($p<.001$) more accurate in the 'yes' response of the half probe (within hemifield) condition ($M=.61$, $SD=.17$) as compared to the 'yes' response of single probe condition ($M=.48$, $SD=.18$). Furthermore, there were a few other significant differences. Participants were significantly ($p<.001$) more accurate in the 'yes' response for the whole probe condition ($M=.87$, $SD=.12$) as compared to the half probe (within hemifield) condition ($M=.61$, $SD=.17$) and single probe condition ($M=.48$, $SD=.18$). Lastly, participants were significantly ($p<.001$) more accurate in the 'yes' responses for the half probe (across hemifield) condition ($M=.63$, $SD=.17$) as compared to the single probe condition ($M=.48$, $SD=.18$). Therefore, participants performed most accurately in the yes response/ no change for the whole probe condition ($M=.87$, $SD=.12$).

4. Discussion

4.1- Summary of results

The study utilised a change detection task to test the effects of ageing on the organisation of VSTM. The change detection task consisted of four probe conditions (whole probe, single probe, half probe (within hemifield) and half probe (across hemifield)) conditions, two groups (young adults and older adults) and two answers (no and yes). There was a significant effect of condition in that overall, participants performed most accurately on the single probe condition. The worst performance was in the half probe (across hemifield) condition for the change detection task. Additionally, there was a significant effect of answers overall, and participants performed more accurately on the yes responses than the no ones.

Even though the study did not predict the answer, there was a considerable difference between yes and no responses. Therefore, the interaction between the condition and answer was studied as well. There was a significant interaction between condition and answer whereby condition seems to influence the answer. Participants significantly performed most accurately in the no response (change between memory display and test display) for the single probe condition and least accurately for the whole probe condition. Additionally, participants performed most accurately in the yes response (no change between memory display and test display) for the whole probe condition and least accurately for the single probe condition. Lastly, there was a significant effect of group (younger adults and older adults), meaning that overall, the younger adults performed better than older adults in the change detection task.

In line with the findings of the prior studies regarding the degradation of the corpus callosum, it was hypothesised that older adults would perform better in the half probe (within hemifield) condition than the half probe (across hemifield) condition. Similarly, based on past studies about the local processing observed in older adults, it was predicted that older adults would perform better in single probe than whole probe conditions. However, there was no significant interaction between the condition and the group. Contrary to the past pieces of literature, the study failed to find any significant interaction between condition and group. This means that even if there was an overall difference between the performance of younger and older adults in the change detection task, that is not anywhere affected by the probe condition. Therefore, the group did not influence by probe conditions, and the group was not influenced by the probe conditions either.

4.2-Principal findings:

The previous study (Brockmole & Logie,2013) found that overall VSTM reduces with age. Hence, older persons were predicted to respond less accurately throughout all four conditions than younger adults. The study found that the younger adults performed better overall than, the older adults, but that did not depend on the conditions. There are several justifications for the lower performance of older adults compared to younger adults. The research results by Adamowicz, J. K. (1976) indicate that older individuals have a reduced ability to interpret VSTM information compared to young people. According to Adamowicz, J. K. (1976), this is due to poorer information processing during the registration phase and a greater vulnerability to interference right after the registration stage. Additionally, working memory (WM) is a high-level cognitive ability that suffers as people age (Li, S.-C. & Rieckmann, A., 2014).

Additionally, Luck, S. J. & Vogel, E. K. (2013) explain that age-related working memory degradation might manifest as a capacity decrease and a deterioration regarding important information. Furthermore, poor attentional filtering has indeed been demonstrated to impair memory performance in older individuals by causing unrelated data to go through more intensely and compete for recollection (Gazzaley et al., 2005), which is another justification for the lower performance of older adults. The significant effect of the group, irrespective of the condition, is also supported by the study of Chalfonte and Johnson (1996), who asked younger and older individuals to spend 90 seconds studying displays of coloured items displayed in different places. Subsequently, respondents had 90 seconds to identify specific aspects of the investigated items (i.e., objects, colours) or their combinations. Memory for integrated characteristics was worse in older individuals than in younger people. Irrespective of the differences between the research design of the past research and this study, it is evident that older adults perform worse than younger adults.

There were a few unpredicted findings. Firstly, there was a significant difference between probe conditions, with participants performing most accurately in the single probe condition and worst accurately on the half probe (across hemifield) condition. This might be because, in single-probed condition, the participant is aware of which item, if any, might change. As a result, the participant only needs to assess the state of a particular item (Rouder et al., 2011). However, the worst performance in half probe (across hemifield) could be due to the lack of hemispheric independence (Delvenne, J. F.,2005). Secondly, there was a significant difference between the answer and an interaction between the probe condition and the answer. However, both these finding points towards limitations and future research. Since it was an online experiment, it was not easy to report if the participants were sure of the answer or if they just guessed the answer. This factor was evaluated by (Rouder et al., 2011). They denoted different letters for the remembered and forgotten items. The rate of change in replies from assuming is denoted as “u” when the item did not exist in memory. “d”, on the other hand, represents the likelihood that the probed item exists in memory. However, the study did not depict any evidence of the organisation of VSTM, as there was no significant interaction between condition and group.

4.3 Applications and limitations of the study:

Although the study reported some significant differences between older adults and younger adults overall, however, despite sufficient evidence from the past literature about the degradation of the corpus callosum in older adults and local processing in older adults, the study failed to show the interaction between probe condition and group (younger adults vs older adults). This reflects the presence of some limitations in the study. Firstly, the task's difficulty might have played a significant role in the low performance of the participants. Complicated tasks elicit a more significant amount of cognitive effort and arousal than simpler ones. At high levels of difficulty, efficiency suffers from a cognitive incapacity to cope with the overload (Adler, R. F., & Benbunan-Fich, R.,2015).

Secondly, it was an online experiment, so several factors could not be controlled, which could have impacted the performance. Even though online experiments have certain benefits like cost-effectiveness, most researchers are concerned about monitoring participants' possible cheating (Reips, U. D. ,2000). Additionally, there is an aim to exert maximum control over the experimental conditions. However, it is not possible to control for all the factors in the online experiment (Reips, U. D. ,2000). Most importantly, there is a real risk of more widespread confusion and forgetting among online participants (Finley, A., & Penningroth, S.,2015). Additionally, limited interaction with participants in the online experiment could lead to difficulties in understanding or retaining instruction (Finley, A., & Penningroth, S.,2015). Furthermore, it was an online experiment with a complex task, and according to Finley, A., & Penningroth, S. (2015), the experimenters should plan for 20-50% data loss for demanding tasks. This level of lost information was approximately 40% in their challenging experiment.

Thirdly, even though there was a difference between yes and no responses in the participants, it was difficult to address whether participants actually recognised the change/no change between the memory and the test display or they did not remember the memory display, and they just guessed the response. Therefore, it was not easy to understand that. For example- For the no response, it was difficult to comment on whether participants recognised the change between the memory and the test display or they did not remember the memory display and just guessed the answer. This factor could have also flawed the results. The fourth limitation of the study was that even though the change detection task is a standard tool for testing working memory capacity for storage, however estimations of memory capacity using this task might be skewed by attention gaps (Feuerstahler et al., 2019). Additionally, the change detection task has the potential to confound identification with search techniques. Older individuals might need more cycle repeats to establish appropriate trust regarding the detection judgement (Costello et al., 2010).

Even though the study has some limitations, it still provides real-life applications. The study predicted that older adults have deteriorated visual short-term memory compared to younger adults, irrespective of probe conditions. Therefore, the study added to existing literature knowledge (e.g., Brockmole & Logie,2013). Therefore, knowing that older adults have visual short-term memory impairment helps forecast and prevent cognitive deficiencies in older adults (Park & Festini,2016) by putting interventions in place. The findings highlight the need to develop interventions to enhance memory consolidation in older adults.

4.4 Future research:

The study provides much scope for future research. Firstly, there is a need to investigate the effect of ageing on visual short-term memory using a more straightforward experimental task in lab settings instead of online experiments. This is because data loss was much more significant for those who participated online than lab-based participants while recalling to complete a potential memory response throughout an ongoing task (Finley, A., & Penningroth, S.,2015). Therefore, more straightforward tasks in lab settings would provide better insight into the performance of older adults because researchers would also be able to control for other factors which could not be controlled for in this online study. Secondly, there is an urgent need for more studies to address within and across hemifield probe conditions in the research of VSTM. This would help address the links to the degradation of the corpus callosum.

Thirdly, Future studies should examine the answer responses in more depth, ensuring participants are not making random guesses which could lead to unsatisfactory results. In this study, it was difficult to comment on whether participants recognised the change/no change between the memory and the test display or did not remember the memory display and just guessed the answer. Fourthly, change detection requires numerous processing phases, throughout which data associated with likely changes are far more probable to be identified than information related to unlikely changes (Beck et al., 2007). Therefore, future research could establish which information processing stage older adults face the most trouble in. Lastly, although exercising has decreased age-related declines in cognitive function, particularly memory and learning, the processes behind this impact are unknown (Snigdha et al., 2014). Therefore, future studies could address better interventions to enhance memory consolidation in older adults.

Overall, the study found some significant differences between older and younger adults in the accuracy of the change detection task, which aligns with past studies. However, the study failed to justify the organisation of VSTM in ageing. Therefore, the study failed to support the previous findings of the local precedence effect and degradation of the corpus callosum in older adults. The study also reported a significant difference in answer responses and a significant effect of probe condition on answer responses.

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