# Investigating Age-Related Changes in Brain Oxygenation During Memory Tasks Using High-Resolution fNIRS

## Abstract

Aging and several neurological illnesses are associated with declining memory function. Simultaneously, cardiovascular disorders may disrupt the regulation of blood flow, which may have an impact on cognitive performance. The purpose of this study was to look into how aging affects blood flow regulation during memory tasks. We used high-resolution functional near-infrared spectroscopy (fNIRS) to measure the pulse wave velocities, slopes and the shape of the blood pressure-related signals in several brain regions during memory tasks in both older and younger persons. This research involves a further examination of the pulse slopes by adding extra channels in LabChart to measure the first and second derivatives and identify the maximum and minimum points on event marker measurements. After extracting the data and calculating the average slopes for each channel, statistics showed that there was no obvious difference between the slopes of each task condition (Nback 1 and Nback 3) and each group (young adults and old adults). Future longitudinal studies should analyze more channels and consider N-back and rest conditions to understand cerebrovascular changes in aging and evaluate interventions aimed at preserving cognitive function, ultimately developing strategies to delay or prevent age-related cognitive decline.

Aging, Memory, Brain Oxygenation, fNIRS, Pulsewave Velocity

## Introduction

Cognitive function and cardiovascular health are two of the many physiological changes that accompany the complex process of aging. Among the cognitive domains impacted by aging, memory is especially prone to deterioration, which presents serious problems for daily functioning and quality of life for older persons (Wang et al., 2023). There is a discernible deterioration in memory function across a range of activities involving the short-term retention and retrieval of information (Kirchner et al., 1958). While some degree of memory loss is thought to be a normal aspect of aging, each person may experience memory loss at a different rate and severity, and neurodegenerative illnesses like vascular dementia and Alzheimer's disease may make the loss worse (Kirchner et al., 1958).

Aging is frequently accompanied by changes in the cardiovascular system, which can have a significant impact on the regulation of cerebral blood flow in addition to cognitive decline. By ensuring the delivery of oxygen and essential nutrients, the complex network of blood vessels supplying the brain plays a crucial role in supporting cognitive function. However, as we age, these vascular networks experience structural and functional alterations such as decreased cerebral autoregulation (Faraco et al., 2017), arterial stiffness (Faraco et al., 2017), and endothelial dysfunction (Faraco et al., 2017). These changes can impair the brain's ability to maintain optimal blood flow in response to metabolic demands, potentially contributing to neurodegeneration and cognitive decline, as supported by studies in the literature (e.g., Faraco et al., 2017; Kim et al., 2021).

Understanding the mechanisms underlying age-related changes in cerebral blood flow regulation holds promise for developing new therapeutic targets and interventions aimed at maintaining cognitive function in older adults. Research indicates that vascular health significantly impacts cognitive performance, with studies demonstrating that interventions improving cerebrovascular function can mitigate cognitive decline (Kim et al., 2021, Viola et al., 2012). Therefore, exploring the complex relationship between cardiovascular health and cognitive function could lead to significant advancements in therapeutic strategies for aging populations. Thus, the current work uses high-resolution functional near-infrared spectroscopy (fNIRS) to analyze the slope of the pulse in old and young adults. We predict that the pulse slope will differ between young and old adults, especially when performing memory tasks. Specifically, we anticipate that older adults will exhibit steeper pulse slopes compared to younger adults, potentially attributable to increased vascular stiffness associated with aging. Additionally, we anticipate that during the performance of memory tasks, brain regions that are involved in vasodilation will experience a shallower slope. We hope to shed light on how aging and the stiffness of veins affect cerebrovascular function and how that affects cognitive aging by testing these theories. According to Ranchod et al. (2023), older adults frequently display compensatory neural activation patterns involving more widespread cortical areas, which may indicate changes in the distribution of brain activity. Novel techniques are required to investigate these changes, such as high-resolution fNIRS, which allows accurate measurement of pulse wave velocities and cerebral oxygenation.

## Methods

### Participants:

A cohort of twenty-two adults, both young and old, participated in the study. The local community was used to recruit participants, who underwent screening for any prior history of neurological or cardiovascular conditions. Before their involvement in the study, each participant provided informed consent.

Data Collection:

While undergoing high-resolution functional near-infrared spectroscopy (fNIRS) scanning, the participants completed a working memory task. The fNIRS equipment used in the investigation comprised optodes applied to the scalp to gauge variations in cerebral oxygenation in 22 different brain areas but we only analyzed the data of 4 areas. Participants in the memory tasks were given instructions to complete two N-back tasks with increasing cognitive loads: a single visuospatial 2-back task and a dual 2-back task. The single 2-back task involved participants comparing a current visual stimulus to the one presented two trials back, requiring active maintenance and updating of information. In the dual 2-back task, participants compared both an auditory and a visual stimulus to those presented two trials back simultaneously, thereby increasing cognitive load and requiring the distribution of attentional resources to multiple processes. These tasks are well-suited for assessing working memory and have shown age-related differences in brain activity and performance (Ranchod et al., 2023).

Pulse Slope Analysis:

The raw fNIRS data were processed using Matlab software to extract fNIRS signals from four channels. One of these channels served as a short channel, and penetrated the scalp and skull, to provide a reference for the other channels. This reference channel helps account for superficial blood flow and improves the accuracy of the measurements in deeper cortical regions.

Pulse slopes were computed from 25 beats by identifying the pulse wave's onset and peak at various measurement sites. Specifically, algorithms were developed to accurately determine the onset of each pulse wave by detecting the peaks and troughs of the second derivative, as outlined by Rakobowchuk et al. (2009). Using macros in LabChart, we extracted the pulse slopes for each channel into a new datasheet. We then performed data cleaning to remove odd data, such as negative slopes or values significantly deviating from the expected range. Finally, we calculated the average slope.

Statistical Analysis:

JASP software was used to perform statistical analyses comparing pulse slopes between Nback 1 and Nback 3, as well as between young and older adults. Participants completed four N-back trials designed to assess their working memory and cognitive load handling. These trials consisted of either 1-back or 3-back tasks, where participants had to monitor and update information by comparing the current stimulus to the one presented either one or three trials earlier, respectively. The 1-back task was intended to serve as a low cognitive load condition, while the 3-back task was implemented to increase task difficulty, thus imposing a higher cognitive load. This setup allowed us to investigate the impact of varying cognitive demands on cerebral blood flow dynamics and pulse slopes.

Comparison of Task Difficulty Conditions:

We compared the pulse slopes recorded during Nback 1 and Nback 3 in young and old adults to examine how cognitive tasks affect the dynamics of cerebral blood flow. Depending on the situation, linear mixed tests were used by the JASP application to examine differences in slopes of signals between task conditions in old and young adults.

During memory tasks, young and older adults' pulse slopes varied, according to a preliminary study using a linear mixed model with participants as a random effect and condition (task difficulty) and groups (young and old) as fixed effects. Because each participant in our design contributed to a minimum of four mean measurements, each of which corresponded to a distinct n-back condition, the use of a linear mixed model was justified. We ran the same linear mixed model for each channel. We looked at the data for each channel and discovered that neither condition nor group had any discernible influence on pulse slope. There was no significant difference between groups ($p > 0.05$) or between conditions ($p > 0.05$) and there were no significant group-by-condition interactions ($p > 0.05$) across all 4 channels assessed (See Figures 1-4). Even while the trend did not approach conventional standards of statistical significance, it did point to possible interactions between group and condition. As you can see in Table 1, each estimate has SE < 0, which quantifies the dispersion of estimates for old and young adults in each task condition (Nback 1 and Nback 3) and shows a lack of statistically significant variations in pulse slopes between young and old adults. Furthermore, several observations had to be omitted from the analysis due to missing data, which required modifications to the statistical model. To be more precise, missing values led to the elimination of some observations, which made it necessary to eliminate some random effects associated with the grouping factor "participant" to preserve the integrity of later analyses.

Even though our results did not approach statistical significance, they still offer important new understandings of the intricate relationships between cerebral blood flow regulation and memory tasks in both young and old adults. The links between aging, cerebrovascular function, and cognitive performance may be further clarified by future studies using bigger sample sizes and improved methodology.

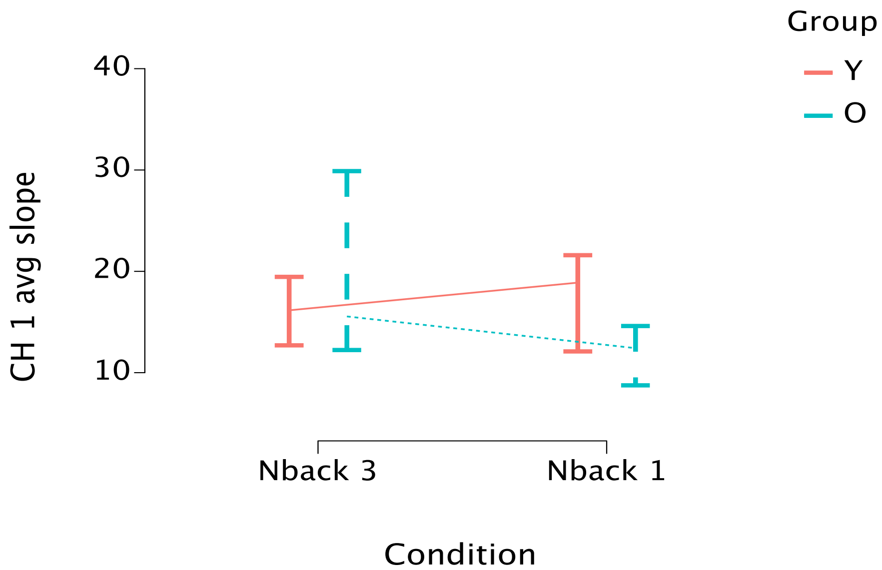


Figure 1. The plot below represents the relationship between the average slope of channel 1 in different task conditions (Nback 1 and Nback 3) among each group (young adults and old adults), which does not show any significant difference.

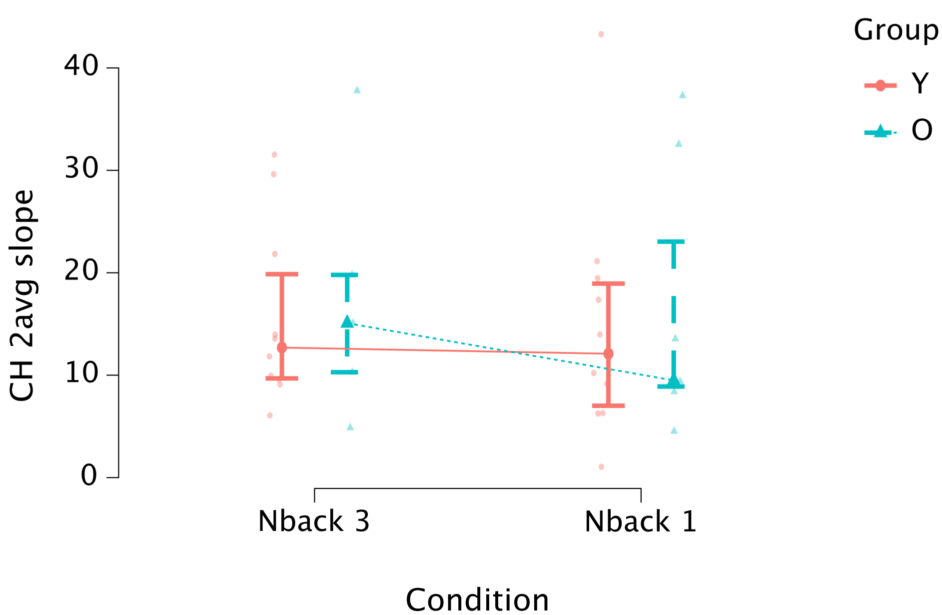


Figure 2. The plot below represents the relationship between the average slope of channel 2 in different task conditions (Nback 1 and Nback 3) among each group (young adults and old adults), which does not show any significant difference.

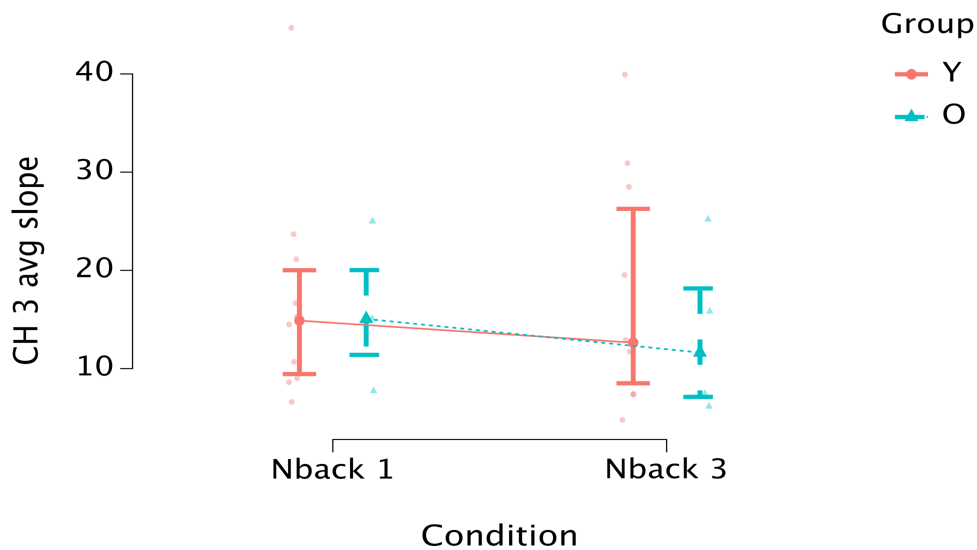


Figure 3. The plot below represents the relationship between the average slope of channel 3 in different task conditions (Nback 1 and Nback 3) among each group (young adults and old adults), which does not show any significant difference.

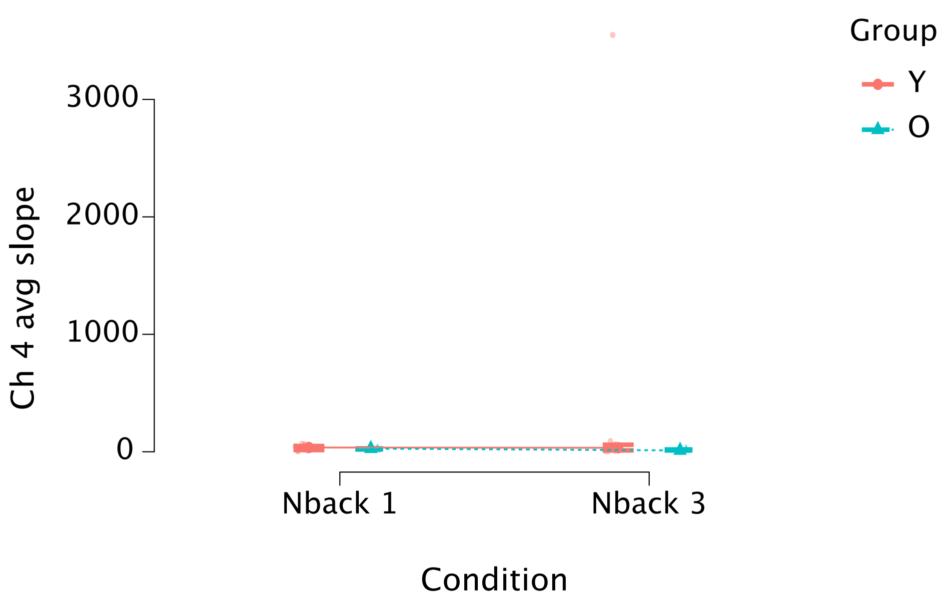


Figure 4. The plot below represents the relationship between the average slope of channel 3 in different task conditions (Nback 1 and Nback 3) among each group (young adults and old adults), which does not show any significant difference.

Table1. This table represents the estimate (Average slope) of each group (yound adults and old adults) in different task conditions (Nback 1 and Nback 3) with SE values.

| | Nback 1 | | Nback 3 | |
|---|---|---|---|---|
| | Estimate | SE | Estimate | SE |
| CH 1 | | | | |
| YA | 16.083 | 2.847 | 14.895 | 2.847 |
| OA | 13.167 | 3.353 | 21.297 | 4.306 |
| CH 2 | | | | |
| YA | 14.737 | 3.410 | 14.506 | 3.410 |
| OA | 16.726 | 4.023 | 17.604 | 4.240 |
| CH 3 | | | | |
| YA | 16.080 | 3.242 | 17.104 | 3.242 |
| OA | 14.400 | 5.282 | 13.785 | 4.945 |
| CH 4 | | | | |
| YA | 34.508 | 224.942 | 385.493 | 224.942 |
| OA | 23.148 | 410.686 | 16.860 | 410.686 |

## Discussion

Our goal was to use high-resolution fNIRS to look at age-related changes in cerebrovascular function during memory exercises. Despite the lack of statistically significant variations in pulse slopes between young and older persons, our results offer important new understandings of the intricate relationships that exist between aging, cerebral blood flow dynamics, and cognitive function. These findings align with previous research suggesting that aging is associated with structural and functional changes in the vascular system, including decreased cerebral autoregulation and arterial stiffness. While not statistically significant, the trends observed in our study warrant further investigation into the mechanisms underlying these changes and their implications for cognitive aging. While our study did not find significant differences in pulse slopes between task conditions among young and old adults, future research with considering more channels and refined methodologies may provide further insights into these dynamics and their impact on cognitive aging.

It is important to acknowledge the limitations of our study, including the relatively small sample size and the presence of missing data. Additionally, our cross-sectional design precludes causal inferences about the relationship between aging, cerebrovascular function, and cognitive decline.

According to Kim et al. (2021), they found a significant association between the slope of $\Delta HbO2$ and vascular reserve in patients with steno-occlusion in the anterior circulation arteries, finding higher slope values and ipsilateral/contralateral $\Delta HbO2$ ratios in patients with deteriorated vascular reserve compared to those with preserved reserve and healthy controls (Kim et al., 2021). Additionally, they observed improvements in these measures following carotid stenting, suggesting their potential to reflect changes in vascular reserve post-intervention. However, our study, which examined pulse slopes during memory tasks in younger and older adults, found no significant differences between task conditions or age groups. While our results did not approach statistical significance, they offer important insights into the relationship between cerebral blood flow regulation and memory tasks.

## Conclusion

Our study offers novel insights into age-related alterations in brain oxygenation during memory tasks using high-resolution fNIRS. By exploring the intricate relationship between cerebrovascular function and cognitive performance in aging populations, we contribute to the growing body of research aimed at understanding and addressing age-related cognitive decline.

Although the findings from our study could not explain the difference between the average pulse slopes in young and old adults during task conditions of Nback 1 and Nback 3, analyzing more channels in future by considering Nback and rest condition would underscore the importance of considering cerebrovascular dynamics in the context of cognitive aging. As the population ages, the prevalence of age-related cognitive decline continues to rise, highlighting the urgent need for interventions aimed at preserving cognitive function in older adults. By elucidating the mechanisms underlying age-related changes in cerebrovascular function, our study lays the groundwork for the development of targeted interventions aimed at mitigating cognitive decline and improving quality of life in aging populations.

In conclusion, our research underscores the critical role of cerebrovascular function in cognitive aging and highlights the potential for interventions targeting cerebrovascular health to preserve cognitive function in older adults. Further research is warranted to explore these mechanisms in greater depth and to develop effective strategies for promoting healthy cognitive aging.

## Future Directions

Continued research should focus on investigating the longitudinal effects of aging on cerebrovascular function and cognitive performance. Longitudinal studies offer the opportunity to track changes in cerebrovascular dynamics over time, providing valuable insights into the progression of age-related cognitive decline and potential intervention strategies. Moreover, further exploration of interventions targeting cerebrovascular health is warranted to assess their efficacy in mitigating age-related cognitive decline. By identifying effective interventions, we can potentially delay or prevent cognitive decline in aging populations, improving quality of life and reducing the burden of age-related cognitive impairment.

In summary, future research endeavours should prioritize studies to elucidate the trajectory of cerebrovascular changes in aging and evaluate the effectiveness of interventions aimed at preserving cognitive function in older adults. These efforts hold promise for advancing our understanding of cognitive aging and developing strategies to promote healthy brain aging.

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