Cognition and the Middle-Aged Brain

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Chapter 8

Concluding remarks

The main objective of this thesis was to investigate age-related brain activation differences underlying learning and memory in middle age using fMRI. In this chapter we reflect on the major findings from this thesis and their implications with regard to current scientific knowledge as well as to the practical consequences of cognitive ageing. Finally, we discuss some overarching methodological considerations.

MAJOR FINDINGS AND THEIR IMPLICATIONS

The studies comprising the present thesis provide evidence for age-related brain activation differences in middle-aged adults, a largely neglected group in the ageing literature. Our findings are, of course, particularly relevant to the focus population of this thesis, namely male school teachers. Age-related activation differences during learning and memory tasks primarily took the form of increased and more dispersed prefrontal cortex activation in middle-aged compared to young adults. In general, activation differences pointed towards the increased recruitment of cognitive resources in relation to the top-down control of attention and cognition, indicative of increased cognitive effort in middle age. Furthermore, we demonstrated that activation patterns in middle-aged adults differed in the context of varying levels of within-task demand, fatigue-inducing sustained task performance and caffeine. These findings provide greater insight into cognitive ageing effects in middle-aged adults.

Scientific implications

Our findings support previous studies showing that age-related functional brain activation changes are already present in middle-aged adults (Grady et al., 2006; Mathis et al., 2009). These differences were found even when cognitive performance at the behavioural level was roughly equivalent in young and middle-aged adults. Hence, subtle differences in behavioural performance belie significant differences in underlying brain activation. Therefore, by relying on the measurement of performance at the behavioural level only, cognitive tasks, including standard (behavioural) neuropsychological tests, probably underestimate age-related cognitive decline in middle age. Functional MRI, on the other hand, confirms the presence of cognitive decline in this age group and provides insight into neural mechanisms underlying middle-aged adults' capacity to maintain an equivalent level of performance to younger adults despite cognitive decline. Findings from the present study indicate that middle-aged adults, like older adults (Reuter-Lorenz and Park, 2010), may maintain a higher level of performance by increasing cognitive effort or adopting alternative strategies – both of which are evident in brain activation changes such as increased and more dispersed activation. Therefore, although changes in cognitive performance at the behavioural level are subtle, it should not be assumed that cognitive ageing effects are of little consequence in middle age. Significant brain activation differences indicate that ageing effects in middle age deserve further attention, especially considering middle-aged adults often still work fulltime in high demand professions. Future research may provide greater insight into cognitive tasks and situations in which middle-aged adults rely on the recruitment of greater cognitive resources than younger adults in order to maintain performance, and the short- and long-term consequences of this increased recruitment.

Our findings show that differences between young and middle-aged adults change when prolonged performance of cognitively demanding tasks is required. Hence, short cognitive tasks may provide only limited insight into the nature of age-related changes. We suggest that, even with the use of fMRI, differences evident on short tasks probably still underestimate the true extent of age-related cognitive changes in middle age. As such, we encourage the adoption of a more 'holistic' approach to the study of cognitive ageing, where factors encountered in 'real-life' are taken into consideration. A more holistic approach may facilitate a better understanding of age-related differences arising, for example, throughout the workday.

The ultimate impact of cognitive ageing in the middle-aged individual probably depends on the interaction between cognitive decline, situational demands (e.g., the level of cognitive challenge) and the state (e.g., fatigue, arousal or stress level) and trait (e.g., intelligence and education level) characteristics of the individual. We demonstrate differences as a result of changes in fatigue, arousal and stress states in relation to induced fatigue and caffeine consumption. Although not directly investigated in this thesis, mood state may also play an important role due to effects on task motivation and effort expenditure. Research suggests a role for 'trait' intelligence in relation to education level in determining the effects of cognitive ageing, with a suggested association between higher education and cognitive reserve (and the facilitation of cognitive flexibility in the use of alternative strategies) (Stern, 2009). The consideration of these factors in future research will increase ecological validity and thus, the usefulness of findings with respect to the real-life implications of cognitive ageing.

Practical implications: the middle-aged adult

A more holistic approach to the study of cognitive ageing, taking factors specific to the individual and their occupation and lifestyle into consideration, is an important step towards the development of interventions to minimise the implications of ageing. By identifying factors associated with exacerbated cognitive impairment or predictors of greater cognitive decline within the healthy range, we can endeavour to 'improve' upon healthy cognitive ageing (Daffner, 2010; Stranahan and Mattson, 2012). Indeed, the popularity of 'brain training' games indicates that there is a high demand for interventions targeting cognitive decline. Cognitive training interventions in ageing adults are still in the relatively early stages of development, but do promise beneficial effects (Boron et al., 2007; Thompson, 2005). However, the extent to which cognition can be enhanced, or the extent to which cognitive ageing effects can be minimised, as a result of brain-training-type interventions may be significantly limited when the individual's lifestyle and workday are not taken into account.

Targeting lifestyle factors such as diet and exercise has shown beneficial effects in relation to cognitive ageing (Daffner, 2010; Stranahan and Mattson, 2012). Beyond the cognitive benefits of a healthy balanced diet, further research is also needed to determine the usefulness of dietary interventions, such as caffeine, in the enhancement of cognitive functioning. Or, in the case of findings regarding caffeine effects in the present study, identifying when products assumed to have a positive effect on performance, may actually be detrimental in some situations.

The development of interventions targeting the workday of middle-aged adults should also be explored (Sluiter, 2006). For example, middle-aged adults' workplace performance may benefit from improved planning of the day such that the prolonged performance of highly demanding tasks is minimised by balancing demands across workdays throughout the week and allowing recovery time with less demanding tasks throughout each day. Furthermore, situations where middle-aged adults are required to work over-time for extended periods, especially with additional pressure to meet deadlines, should be avoided.

The development of interventions to enhance cognitive function in middle-aged adults not only has implications for the productivity of a large proportion of the working population; it also has implications for workplace satisfaction and general quality of life in this population. For example, an awareness and acceptance of the presence of cognitive decline in middle age may be important to the expectations held by the middle-aged individual and others with regard to workplace performance. Middle-aged adults in highly demanding occupations may be faced with the unrealistic expectation of keeping up with their younger counterparts in terms of the level of cognitive demand and number of hours in the workday. The failure to adjust workplace expectations in relation to cognitive decline may lead to the exhaustion of cognitive resources, fatigue and poorer workplace performance in middle-aged adults. An inability to meet their own expectations, as well as the expectations of others, may also contribute to the development of feelings of frustration, workplace dissatisfaction and eventually to the increased incidence of burnout in the middle-aged population (Ahola et al., 2006; Lindblom et al., 2006).

Furthermore, adjusting the workday so that daily demands do not result in the exhaustion of cognitive resources in middle-aged adults on a daily basis may also prevent the development of more long-term fatigue complaints. Studies in patient populations suggest that although the exertion of increased cognitive effort facilitates the maintenance of a higher level of performance in the short-term, it may underlie the development of chronic fatigue complaints in the long-term (Cook et al., 2007; DeLuca et al., 2008; Kohl et al., 2009). Indeed, it has been suggested that long-term fatigue complaints may be an early indicator of cognitive ageing (Avlund, 2010). However, we suggest that the relationship between ageing and fatigue complaints may be better described as somewhat of a vicious circle relationship, with fatigue leading to exacerbated cognitive impairment, necessitating the exertion of increased compensatory cognitive effort, and consequentially to more severe fatigue-related complaints.

Practical implications: the middle-aged school teacher

In the following paragraphs we consider the practical implications of our findings for middle-aged school teachers, in particular. Middle-aged school teachers have the benefit of greater experience and knowledge with regard to numerous aspects of their job, allowing them to perform many tasks intuitively. However, the ever-changing education system and the changing needs of new generations of pupils, requires middle-aged teachers to constantly adapt their teaching practices. Middle-aged school teachers commonly experience greater difficulty meeting expectations in relation to the necessity to continually keep up-to-date with new developments in their own teaching area as well as the latest educational trends in teaching and behaviour management strategies. The need to master new technologies (such as the use of computers, new computer software, media or products such as tablet computers in schools) also poses a particular challenge to middle-aged teachers, and may even lead to situations in which teachers actually find themselves less competent in the use of a particular technological innovation than their own pupils. Furthermore, the increasing generation gap between middle-aged teachers and their pupils may contribute to pupils treating the teacher with even less respect in an educational climate where disciplinary issues already place a greater strain on the teacher's emotional resources than ever before. Hence, although their increased experience may make some aspects of teaching less demanding for middle-aged than for young teachers, cognitive ageing effects may make other aspects more demanding. Therefore, it is important to recognise that middle-aged teachers may need extra support with various aspects of this highly demand occupation. Especially considering that, on the basis of their more extensive teaching experience, middle-aged teachers are often allocated the more difficult and demanding classes.

Middle-aged teachers may benefit from workday interventions that focus on providing support with regard to tasks that they find more demanding than young teachers, as well as the minimisation of the sustained performance of demanding tasks. As described above, middle-aged teachers find it more demanding than young teachers to keep up with various types of changes in their profession. The extra effort required by middle-aged teachers to keep up with changes is probably an important contributor to greater resistance to change in this age-group (Hargreaves, 2005). Therefore, middle-aged teachers may benefit from change management strategies tailored to their specific needs in order to promote optimal teacher learning. Such change management strategies may include working one-on-one with middle-aged teachers to provide coaching or mentoring in difficult areas, as well as providing a plan for the step-by-step implementation of changes. Similarly, the encouragement of collaborations between young and older teachers within the professional learning community may foster working relationships in which each teacher benefits from the strengths of the other. As previously mentioned, recognising the differing strengths and weaknesses of young and middle-aged teachers, and adjusting performance expectations and support strategies accordingly, is not only important to enhancing workplace performance, it is probably also an important step towards addressing the relatively high incidence of burnout in the teaching profession (Hakanen et al., 2006).

Minimising the sustained performance of demanding tasks may be achieved by improved planning of the workday, or specific lessons, such that demanding classes are followed by a break, or a less demanding class, and teachers alternate between demanding and less demanding teaching strategies within a lesson. Furthermore, some middle-aged teachers may benefit from options that lower their teaching load, such as teaching part-time or moving into more administrative or coordinating roles within the education system. Finally, middle-aged teachers may benefit from increased flexibility with regard to working hours during particularly busy periods, such as during end-of-term assessments. For example, one school principal reported encouraging stressed teachers to take a day off (or 'sick leave'), and employed a relief teacher to cover their teaching load, in order to prevent the teacher developing an actual (mental) health issue.

METHODOLOGICAL CONSIDERATIONS

fMRI methodology

Although fMRI has led to substantially greater insight into the mechanisms underlying, and factors interacting with, cognitive ageing, several methodological considerations must be taken into account in relation to the studies comprising this thesis. Importantly, the comparison of young and older adults using fMRI is complicated by age-related differences in neurovascular coupling, morphology and variance/noise (D'Esposito et al., 2003; Samanez-Larkin and D'Esposito, 2008). We endeavoured to minimise within-group variance by testing a homogeneous group of right-handed, Dutch males with a high level of education from predominantly the same occupation group (school teachers), within restricted age-ranges. By focusing on right-handed male school teachers we minimised variance in the structural and functional images. Moreover, variability in the expected functional activation response to our induced fatigue intervention, in particular, was minimised as a result of uniformity in education level and occupation-related experience with cognitive task type and the level of task demand. Furthermore, variance in the response to a cup of coffee was minimised by restricting the sample to males with daily caffeine consumption levels that fell within a specific range. Increasing the homogeneity of small groups improves group averaging (by increasing co-localisation of cortical areas) and probably improved the reliability of our results compared to studies that do not attempt to minimise within-group variance, especially considering our relatively small sample sizes. This unique approach to the investigation of cognitive ageing in healthy participants allows us to draw stronger conclusions regarding ageing effects within this population. Although such an approach may appear to limit the generalisability of our findings, there is no reason to expect that the reported effects are not also present in females, other occupation groups or populations with a lower education level. Indeed, we may expect greater effects in, for example, individuals with a lower education level in association with a lower level of cognitive reserve (Stern, 2009).

The increase in variance/noise in older adults necessitates testing a larger group of older adults than the group of younger adults. Although we did test somewhat more middle-aged adults in the first study, our studies would have been improved by the inclusion of more participants; especially considering that we did find that middle-aged adults moved more in the scanner than younger adults. Unfortunately, middle-aged adults working fulltime in demanding professions whilst, more often than not, also raising a family are a difficult population group to recruit, especially for studies requiring a relatively large time investment. In total, our study required a time investment of at least eight hours from each participant. Despite extensive recruitment initiatives, difficulties finding suitable participants, willing and able to volunteer, meant that recruitment of a larger group was not possible within the time constraints of this project (the project had to be completed within 48 months). Especially considering that we did not want to sacrifice our unique results by broadening our inclusion criteria any more than was strictly necessary.

On the other hand, by testing this population group, regardless of our somewhat small sample sizes, our study makes an important contribution to imaging literature dominated by studies in (far more easily recruited) student populations and retired older adults (60 + years old) by providing insight into age-related brain activation differences in the working middle-aged population. The continued neglect of working middle-aged adults and over-reliance on young-student vs. old-retirees comparisons in ageing literature would be detrimental to our understanding of the ageing process in general and of ageing effects in a large proportion of the workforce. Hence, we suggest that future studies should pay more attention to middle-aged adults, despite the anticipated increased recruitment difficulties.

Differences in neurovascular coupling may affect the BOLD response in general, and are thus a potential confounder in the investigation of the main effect of age on neural activity. However, in the present study, we used tasks in which it was possible to examine the interaction between age and within task conditions (such as working memory load), as well as between repeated measures. Thus, as findings represented the magnitude of changes within each individual, rather than direct comparison of conditions between individuals, differences are unlikely to be due to effects of neurovascular coupling. Furthermore, we examined the correlation between brain activation and cognitive performance, as the relationship between these factors provides greater support for the attribution of BOLD differences to differences in neural activation. Differences in brain morphology as a result of structural ageing effects such as grey matter atrophy may also pose a problem for comparisons between young and middle-aged adults (although less so than the more common comparison in ageing studies between adults younger than 25 years and older than 60 years). We took care to minimise this problem by ensuring that each individual's scans were well normalised.

The population sample

Finally, it is important to consider the nature of the population tested. Functional MRI research is restricted, at the very least, to individuals who do not have MRI contraindications, such as any metal in the body. We further restricted our sample to individuals with no history of serious physical or psychiatric illness. Hence, our sample represents somewhat of a 'super' group of middle-aged adults, especially considering that they were also highly educated, worked fulltime in a cognitively demanding occupation, and were still enthusiastic about making time in their busy lives to participate in our study. It may be expected that middle-aged adults from population groups with a lower level of education (and an associated lower level of cognitive reserve), less cognitively demanding occupations (thus with less experience with cognitively demanding tasks), who are no longer working fulltime, may differ in the level of available cognitive resources and thus provide different results. Moreover, it is possible that school teachers who did not volunteer may have felt that participating in the study would be too much for them on top of their already exhausting week. Hence, those who did participate may also represent a group of 'super-teachers' in whom cognitive decline may have been less apparent than in teachers who chose not to volunteer.

On the other hand, a potential concern in relation to individuals interested in participating in an fMRI or 'memory' study, is the possibility that those who volunteer over-represent the proportion of the ageing population who are worried about their brain or memory function. We endeavoured to avoid this sampling bias by including a question in the screening questionnaire regarding the individual's motivation to participate in our study. Fortunately, our participants were predominantly individuals who were interested in neuroscientific research and considered it important to contribute to this research. Therefore, we are more inclined towards the possibility that our participants represent somewhat of a 'super', highly motivated group than the possibility that they represent the 'worried well' or those with more apparent cognitive decline. Hence, we expect that our findings may provide a conservative indication of ageing effects in the average (less-than-super) middle-aged adult.

CONCLUSIONS

Insight into the underlying mechanisms and exacerbating and ameliorating factors in relation to cognitive ageing in middle age is important to our understanding of the cognitive ageing process and to the development of interventions to enhance cognitive performance in this age group. Neuroimaging methods, such as fMRI, are essential to future research in this area as behavioural studies provide a limited picture of the effects of age-related cognitive decline. Furthermore, ageing studies with greater ecological validity, that take a more holistic approach to the study of cognitive ageing, are an important step towards a better understanding of the 'real life' effects of cognitive decline. Moreover, by focusing on specific occupation groups, a more individualised picture of the effect of cognitive ageing can be achieved and the impact of ageing on various occupation-specific tasks can be identified, facilitating the development of occupation-tailored interventions. Interventions that increase workplace performance and improve well-being in this age group will probably have a great societal impact, as, in our ageing society, middle-aged adults make up a large proportion of the workforce. Therefore, although working middle-aged adults are more difficult to recruit than students or retirees, more studies such as ours are warranted.

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