

# Aging, Neuropsychology, and Cognition

A Journal on Normal and Dysfunctional Development

ISSN: 1382-5585 (Print) 1744-4128 (Online) Journal homepage: <http://www.tandfonline.com/loi/nanc20>

## The protective role of long-term meditation on the decline of the executive component of attention in aging: a preliminary cross-sectional study

Marco Sperduti, Dominique Makowski & Pascale Piolino

To cite this article: Marco Sperduti, Dominique Makowski & Pascale Piolino (2016): The protective role of long-term meditation on the decline of the executive component of attention in aging: a preliminary cross-sectional study, *Aging, Neuropsychology, and Cognition*, DOI: [10.1080/13825585.2016.1159652](https://doi.org/10.1080/13825585.2016.1159652)

To link to this article: <http://dx.doi.org/10.1080/13825585.2016.1159652>



Published online: 16 Mar 2016.



Submit your article to this journal [↗](#)



View related articles [↗](#)



View Crossmark data [↗](#)

## The protective role of long-term meditation on the decline of the executive component of attention in aging: a preliminary cross-sectional study

Marco Sperduti<sup>a,b</sup>, Dominique Makowski<sup>a,b</sup> and Pascale Piolino<sup>a,b,c</sup>

<sup>a</sup>Memory and Cognition Laboratory, Institute of Psychology, Paris Descartes University, Sorbonne Paris Cité, Boulogne-Billancourt, France; <sup>b</sup>Center for Psychiatry and Neurosciences, INSERM UMR S894, Paris, France; <sup>c</sup>Institut Universitaire de France (IUF), Paris, France

### ABSTRACT

Life expectancy is constantly increasing. However, a longer life not always corresponds to a healthier life. Indeed, even normal aging is associated with a decline in different cognitive functions. It has been proposed that a central mechanism that could contribute to this widespread cognitive decline is an ineffective inhibitory attentional control. Meditation, to the other hand, has been associated, in young adults, to enhancement of several attentional processes. Nevertheless, attention is not a unitary construct. An influential model proposed the distinction of three subsystems: the alerting (the ability to reach and maintain a vigilance state), the orienting (the capacity of focusing attention on a subset of stimuli), and the conflict resolution or executive component (the ability to resolve conflict or allocate limited resources between competing stimuli). Here, we investigated, employing the Attentional Network Task (ANT), the specific impact of age on these three subcomponents, and the protective role of long-term meditation testing a group of older adults naïve to meditation, a group of age-matched adults with long-term practice of meditation, and a group of young adults with no previous meditation experience. We reported a specific decline of the efficiency of the executive component in elderly that was not observed in age-matched meditators. Our results are encouraging for the investigation of the potential beneficial impact of meditation on other cognitive processes that decline in aging such as memory. Moreover, they could inform geriatric healthcare prevention and intervention strategies, proposing a new approach for cognitive remediation in elderly populations.

### ARTICLE HISTORY

Received 7 September 2015  
Accepted 24 February 2016

### KEYWORDS

Aging; attention; conflict resolution; executive functions; meditation

## Introduction

Life expectancy is constantly increasing in the developed countries due to medical, hygiene and socioeconomic advances. Following the World Health Organization (WHO), the median age of the European population is already the highest in the world and the proportion of citizens aged 65 years or older is expected to increase from the 14% in

2010 to the 25% in 2050, and people aged 85 years or older are projected to rise from 14 million in 2010 to 40 million in 2050. Unfortunately, a longer life not always corresponds to a healthier life. Indeed, aging is associated with growing risk factors for ill health associated with societal factors (isolation, maltreatment), and neurodegenerative diseases. As stated by the WHO, one major societal challenge is to build policies that support people of all ages to maintain a maximum health and functional capacity throughout their lives and to empower all people to live and die in dignity. Thus, finding efficient intervention that could prolong elderly's autonomy could be a pivotal societal challenge.

Indeed, even healthy aging is characterized by an important cognitive decline in different aspects of cognition. It has been proposed that a central mechanism that could contribute to this widespread cognitive decline is an ineffective inhibitory attentional control (). This view is in accordance with reduced top-down attentional control reported in older adults (Gazzaley & D'esposito, 2007), and with their difficulties in tasks requiring conflict resolution (Aschenbrenner & Balota, 2015; Zhu, Zacks, & Slade, 2010), or limited allocation of attentional resources (Maciokas & Crognale, 2003).

Nevertheless, attention is not a unitary construct. An influent model (Posner & Petersen, 1990) proposes the distinction between the alerting (the ability to reach and maintain a vigilance state), the orienting (the capacity of focusing attention on a subset of stimuli), and the conflict resolution or executive component (the ability to resolve conflict or allocate limited resources between competing stimuli). These subsystems have been characterized at the behavioral, neuronal, and neurochemical level (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002). The alerting component is associated with activation in a right fronto-parietal network, and it has been linked to the norepinephrine system, the orienting component recruits posterior areas, such as the superior parietal lobe and temporo-parietal junction (TPJ), and the frontal eye-field, and is modulated by the cholinergic system. Finally, the executive component is sustained by lateral and medial frontal structures, such as the dorsolateral prefrontal cortex (dlPFC) and the anterior cingulate cortex (ACC), and by the inferior parietal lobule (IPL), and it has been associated with the dopaminergic system (Fan et al., 2005; Fossella, Posner, Fan, Swanson, & Pfaff, 2002). Interestingly, Fan et al. (2002) proposed a single task, the ANT, allowing testing the efficiency of these three systems. The few studies employing this task to investigate age-related changes in attention reported that the most impaired component is the executive one (Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010; Zhou, Fan, Lee, Wang, & Wang, 2011; but see also Fernandez-Duque & Black, 2006; Jennings, Dagenbach, Engle, & Funke, 2007).

Meditation refers to a series of practices whose aim is the voluntary control of the attentional focus. A distinction between focused attention (FA) and open monitoring (OM) techniques has been proposed (Lutz, Slagter, Dunne, & Davidson, 2008). FA practices are based on the concentration of attention on a particular external, corporal or mental object while ignoring all irrelevant stimuli. At the opposite, OM techniques try to enlarge the attentional focus to all incoming sensations, emotions and thoughts from moment to moment without focusing on any of them with a non-judgmental attitude (Lutz et al., 2008). FA is thought to not only train sustained attention, but also to develop three attentional skills: the vigilance and monitoring of distracting stimuli beyond the

intended focus of attention, the disengagement of attention from distracting stimuli once the mind has wandered, and the redirection of FA on the intended object. Direct evidence for this model have been recently reported in a neuroimaging study showing that the activity of brain networks subserving these cognitive functions was modulated by the amount of meditation practice during the lifespan (Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012). OM meditation involves more monitoring processes of one's own phenomenological experience and is thought to develop awareness and non-reactive meta-cognitive monitoring (Lutz et al., 2008).

It has been shown that meditation can improve different cognitive abilities. One of the most investigated domains, not surprisingly, is that of attentional improvement after either long- or short-term meditative practice. Different researchers have employed the ANT (Fan et al., 2002) to investigate the specific impact of meditation on the three attentional subcomponents defined above. Results on expert mindfulness meditators showed better performances in the orienting component and a trend to better executive attention (. In another study, Jha, Krompinger, and Baime (2007) investigated whether different stages of meditation expertise enhance specific attentional networks. They compared performances between a group of expert meditators, a group that followed an 8-week mindfulness training, and a control group. They further measured the performance between the three groups at baseline ( $T_1$ ) and after a 1-month meditative retreat for the meditators group, the 8-week training for the mindfulness group, and no treatment for the control group ( $T_2$ ). Their findings showed that at  $T_1$ , experts had better performance in conflict monitoring compared to the other two groups, while at  $T_2$  the mindfulness group showed enhanced orienting, and the difference in the executive component compared with experts was no longer significant. In the same vein, Tang et al. (2007) reported that even a short 5-days meditation training enhanced performance in conflict monitoring.

Other results in accordance with a benefit of meditation on the executive component of attention come from a study investigating the attentional blink effect. This effect consists on the fact that if two target stimuli ( $t_1$  and  $t_2$ ) are presented in rapid succession, normally the  $t_2$  is not detected (Raymond, Shapiro, & Arnell, 1992). Slagter et al. (2007) reported that after 3-months intensive meditative practice the attentional blink was reduced as a result of diminished resources allocation to  $t_1$ . The same pattern of results was found in a cross-sectional study comparing a group of expert meditators (range of practice between 1 and 29 years) with a control group that had never practiced meditation (van Leeuwen, Müller, & Melloni, 2009). Moreover, Chan and Woollacott (2007) reported, in a group of expert meditators, a reduction of the interference score in the Stroop task, but not in the Global-Local Letters task that were considered by the authors as measures of executive and orienting attention, respectively.

Beyond behavioral findings, converging evidences from functional (for a meta-analysis see Tomasino, Fregona, Skrap, & Fabbro, 2012) and structural neuroimaging studies (for a meta-analysis see Fox et al., 2014) have reported activations in areas supporting attentional functions during meditation practice, and long-lasting structural gray- and white-matter modification in the same networks, respectively.

Taken together, these results suggest that the executive component is the most affected by meditation, even if some studies reported better performance on the orienting or the alerting component (van den Hurk et al., 2010). It should be noted,

however, that participants in the van den Hurk et al. (2010)'s study had a much longer meditation experience (mean 14.5 years). This could suggest that the executive system is the first attentional component to benefit of meditation training and that longer practice is needed to achieve improvement in the other components.

To summarize, to the one hand, reduced attentional processes have been reported in elderly, and it has been proposed that this mechanism could explain the age-related decline in other cognitive domains (e.g., memory; Gazzaley & D'Esposito, 2007). To the other hand, converging findings suggest a beneficial effect of meditation on attentional processes, suggesting that this practice could have a potential protective role against the cognitive decline observed in elderly. Nevertheless, while several authors have recently underlined the interest of studying the effect of meditation on the cognitive functions in older population (Gard, Hölzel, & Lazar, 2014; Luders, 2014; Marciniak et al., 2014; Tang, Posner, & Rothbart, 2014), only few studies directly addressed this question.

Pagnoni and Cekic (2007) showed a negative correlation between age and performance on a sustained attention task in control participants, but not in meditators. Hawkes, Manselle, and Woollacott (2014) reported that the difference in reaction time switch cost between meditation practitioners and a control group remained significant even after controlling for age, even if performance in the task was negatively correlated with age. These results suggest that aging could have a smaller impact on task-switching performance in the meditation group. Another study showed a reduced attentional blink in middle-aged meditators, compared with an aged matched control group (van Leeuwen et al., 2009). More recently, Prakash et al. (2012) showed better performances in different cognitive skills, comprising working memory, cognitive flexibility and inhibition (Stroop), in elderly practicing meditators (>55 years) compared to an age-matched control group that did not practice meditation.

These preliminary findings are encouraging, and suggest that meditation can prevent the age-related cognitive decline. Here we tested the hypothesis that long-term meditation practice could prevent the decline of specific attentional subsystems. In particular, in accordance with the aforementioned literature, we predicted that aging would be linked with a specific reduction of the efficiency of the executive component, and that this effect would not be present in age-matched expert meditators. To test our hypothesis, we administered the Attentional Networks Task (Fan et al., 2002) on three groups of participants: older adults naïve to the practice of meditation, older adults with an extensive practice of meditation, and young adults naïve to the practice of meditation.

## Material and methods

### Participants

Sixteen older adults naïve to meditation (OAN; mean age  $67.12 \pm 5.62$  years), 16 older adults expert in meditation (OAE; mean age  $67.69 \pm 7.22$  years), and 19 young adults naïve to meditation (YAN; mean age  $27.16 \pm 3.09$  years) participated in the study. The three groups did not differ with respect of years of education ( $F[2,48] = 0.32, p > 0.05$ ). The two older groups did not differ in general cognitive functioning ( $t(30) = 0.22, p > 0.05$ ) as assessed by the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; French translation, Kalafat, Hugonot-Diener, & Poitrenaud, 2003). For

**Table 1.** Demographic data.

	OAN	OAE	YAN
Participants	16 (8 female)	16 (10 female)	19 (9 female)
Age	67.12 ± 5.62	67.69 ± 7.22	27.16 ± 3.09
Education	14.87 ± 2.58	15.5 ± 2.48	15.26 ± 1.63
MMSE	29.37 ± 0.96	29.44 ± 0.63	
Meditation Experience		25.5 ± 9.9	

OAN, old adults naïve to meditation experience; OAE, old adults expert in meditation; YAN, young adults naïve to meditation experience; MMSE, mini mental state examination.

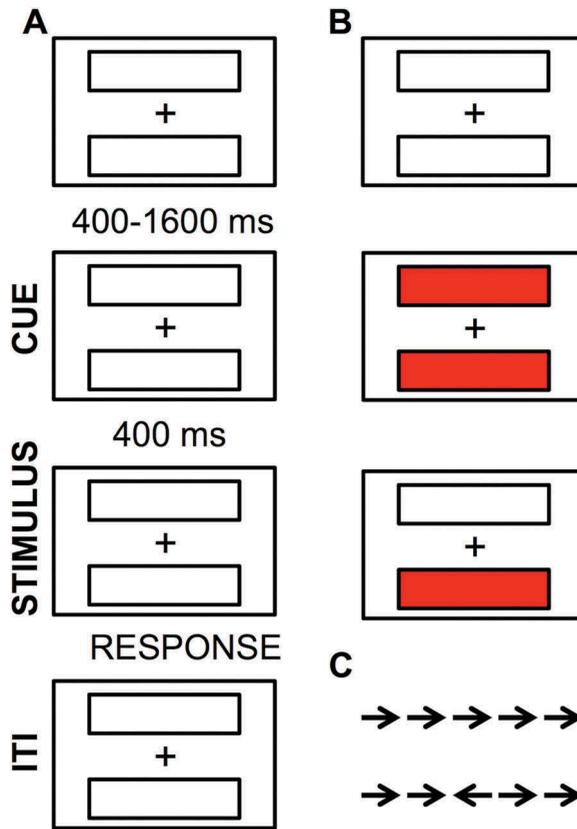
detailed demographic and basic neuropsychological characteristics of the sample see [Table 1](#). OAE were recruited from local meditation centers, and they had a mean of  $22.5 \pm 9.9$  years (range 11–44 years) of regular practice. Twelve practiced in the Zen tradition and four practiced in the Tibetan tradition. Both traditions emphasize OM techniques, even if FA practices are also employed. All participants were native French speakers. All subjects signed a written informed consent before being enrolled as volunteers in the study.

### Attentional network task

We employed a modified version of the ANT (Fan et al., 2002). Each trial started with the presentation, on a white background, of a black fixation cross at the centre of the screen and two empty rectangles positioned above and under the fixation cross. After a variable random interval (400–1600 ms) a cue, consisting in the change of color (red) of the rectangles, was presented for 100 ms, and was followed after a fixed duration of 400 ms by the presentation of the stimulus in one of the two rectangles. The trial ended with subjects' response and was followed by a variable inter trial interval (2000–4000 ms). There were three cuing conditions: no cue (NC), double cue (DC), and spatial cue (SC). The stimulus was composed of one central arrow (the target) surrounded by four arrows (flankers). The flankers could point in the same (congruent) or in the opposite (incongruent) direction of the target. Congruent (CO) and incongruent (IN) trials were randomly presented. The direction of the central arrow (left or right), and the position of the stimulus (up or down rectangle) were equally presented across the experimental conditions. For a schematic representation of the protocol see [Figure 1](#). The experiment was composed by a total of 96 trials. Subjects were instructed to continuously fix the central cross, and to respond with the right or the left arrow of the computer keyboard to indicate the direction of the target as fast as possible. Before starting the experiment, they participated in a training session composed of 12 trials. The total duration of the task was about 15 min.

The efficiency of the attentional networks was computed as follows: for the alerting (ALE) we subtracted reaction times in the DC from those in the NC condition, for the orienting (ORI) we subtracted reaction times in the SC from those in the DC condition, for the executive (EXE) component we subtracted reaction times in the CO from those in the IN condition. To account for slowing in reaction time with age, we also computed corrected-ratio scores as follows:  $ALE_{corrected} = ALE/DC$ ;  $ORI_{corrected} = ORI/SC$ ;  $EXE_{corrected} = EXE/CO$ .

Presentation of the stimuli and recording of data were automatically accomplished using PsychoPy© (Peirce, 2007).



**Figure 1.** Schematic representation of the protocol. (A) The time course of the events in one trial. (B) The three cuing conditions. (C) A congruent (up) and an incongruent (down) stimulus. [To view this figure in color, please see the online version of this journal.]

## Results

We first run a mixed ANOVA with three cuing conditions (NC–DC–SC)  $\times$  2 congruency (CO–IN) as within subjects' factors, and three groups (OAN–OAE–YAN) as between subjects' factors on reaction time. We found a significant main effect of group,  $F(2,45) = 4.13$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.15$ . Post hoc comparisons (Fisher's LSD) showed that the OAN was slower than YAN group ( $p < 0.01$ ), while the differences between OAN and OAE and OAE and YAN were not significant (both  $p > 0.1$ ). The main effect of cuing conditions was also significant,  $F(2,90) = 106.64$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.70$ , with reaction times being higher in the NC compared to DC and SC conditions (both  $p < 0.001$ ), and higher in the DC compared to the SC condition ( $p < 0.001$ ). Finally, the main effect of congruency was significant,  $F(1,45) = 60.18$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.57$ , with reaction times being longer in the IN compared to the CO condition. Descriptive statistics are reported in Table 2.

We computed separate one-way ANOVA with group as a between subject factors on the ALE, ORI, and EXE scores. Moreover, we run the same analyses on the corrected scores.

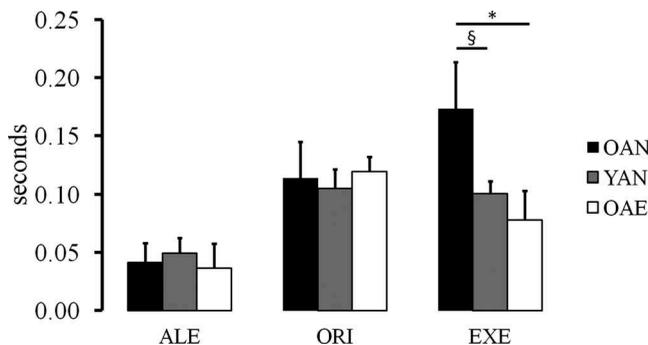
**Table 2.** Descriptive statistics for reactions time for all the experimental conditions.

	No cue		Double cue		Spatial cue	
	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
OAN	0.98 [0.51]	1.14 [0.65]	0.93 [0.52]	1.11 [0.65]	0.84 [0.59]	0.99 [0.72]
OAE	0.85 [0.15]	0.95 [0.18]	0.80 [0.16]	0.90 [0.17]	0.68 [0.13]	0.78 [0.18]
YAN	0.65 [0.09]	0.75 [0.12]	0.59 [0.10]	0.71 [0.13]	0.52 [0.09]	0.59 [0.11]

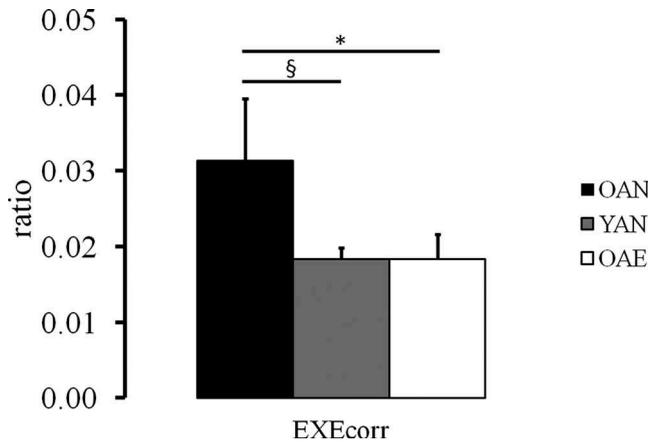
The mean and the standard deviation, in brackets, of reaction times expressed in seconds for all conditions in the three groups are reported. OAN, old adults naïve to meditation; OAE, old adults expert in meditation; YAN, young adults naïve to meditation.

The ANOVA on the ALE,  $F(2,48) = 0.15$ ,  $p > 0.05$ ,  $\eta_p^2 = 0.006$ , and on the ORI,  $F(2,48) = 0.12$ ,  $p > 0.05$ ,  $\eta_p^2 = 0.005$ , scores did not reveal a significant effect of group. To the other hand, the ANOVA on the EXE score revealed a significant effect of group,  $F(2,48) = 3.38$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.12$ . Post hoc (Fisher's LSD) comparison showed that the difference between OAN and OAE was significant ( $p < 0.05$ ,  $d = 0.67$ ), and that there was a strong tendency for the difference between OAN and YAN ( $p = 0.055$ ,  $d = 0.59$ ). The difference between OAE and YAN was not significant ( $p > 0.05$ ,  $d = 0.25$ ). This result showed that the efficiency of the EXE networks is reduced in OAN, but not in YAN. See [Figure 2](#) for a graphical representation of the results.

The ANOVA on the ALE<sub>corrected</sub>,  $F(2,48) = 0.94$ ,  $p > 0.05$ ,  $\eta_p^2 = 0.04$ , and on the ORI<sub>corrected</sub>,  $F(2,48) = 0.52$ ,  $p > 0.05$ ,  $\eta_p^2 = 0.02$ , scores did not reveal a significant effect of group. The ANOVA on the EXE<sub>corrected</sub> score showed a strong tendency toward significance,  $F(2,48) = 2.51$ ,  $p = 0.09$ ,  $\eta_p^2 = 0.10$ . Planned comparisons revealed that the difference between the OAN and OAE group was significant ( $p < 0.05$ ,  $d = 0.59$ ), with the former group having a higher score ( $0.031 \pm 0.033$ ) than the latter ( $0.016 \pm 0.013$ ). The difference between OAN and YAN showed a tendency toward significance ( $p = 0.08$ ,  $d = 0.54$ ), YAN had a lower score ( $0.018 \pm 0.006$ ) than OAN. The difference between OAE and YAN was not significant ( $p > 0.1$ ,  $d = 0.19$ ). See [Figure 3](#) for a graphical representation of the results.



**Figure 2.** Results of the one-way ANOVA on the three attentional networks. Older adults naïve to meditation (OAN) are represented in black, Young Adults naïve to meditation (YAN) in gray, and older adults experts (OAE) in meditation in white. Error bars represent standard error mean (SEM).  $^{\S}p = 0.055$ ,  $*p < 0.05$ .



**Figure 3.** Results of the one-way ANOVA on the executive corrected score. Older adults naive to meditation (OAN) are represented in black, young adults naive to meditation (YAN) in grey, and older adults experts (OAE) in meditation in white. Error bars represent standard error mean (SEM).  $^{\S}p = 0.08$ ,  $*p < 0.05$ .

## Discussion

The present study investigated the possible beneficial impact of long-term meditation on the decline of attentional processes observed in aging. We used the ANT (Fan et al., 2002) to specifically assess the impact of aging and the effect of meditation on three attentional subcomponents previously described in the literature (Fan et al., 2002; Posner & Petersen, 1990): the alerting, the orienting, and the executive network. According to our hypothesis and previous findings (Mahoney et al., 2010; Zhou et al., 2011), we reported a reduction of the efficiency of attention in elderly, compared to both young adults and older expert meditators that was specific to the executive component. Most strikingly, older meditators' performance was indistinguishable from that of young adults. We found a similar pattern of results even when adjusting for aging-related slowing in reaction time. Indeed, even if the ANOVA on the executive corrected score only showed a trend toward significance, planned comparison demonstrated a significant difference between meditators and elderly as well as a trend toward a difference between elderly and young. Moreover, the effect sizes were moderate to high for both the differences between meditators and elderly and between young and elderly, and these effects were of the same magnitude when comparing raw difference scores to corrected scores.

Our findings are in line with previously reported evidence of a specific effect of meditation on the executive component of attention, and extend these findings to an older population. Moreover, in accordance with a handful of precedent studies, reporting a benefit of meditation on sustained attention and its underlying neural substrates (Pagnoni & Celic, 2007), on the efficiency of allocation of attentional resources (Maciokas & Crognale, 2003), and on performance on executive task (Prakash et al., 2012) in elderly, our data corroborate the idea that meditation could play a protective role against the age-related cognitive decline.

Tasks involving attentional control and conflict resolution have been repeatedly associated with brain activation in a fronto-parietal network comprising the dorsolateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), and the inferior parietal lobule (IPL) (Cieslik et al., 2015; Fan et al., 2005; Nee, Wager, & Jonides, 2007). These regions, in particular those within the frontal lobe, are among the most precociously and severely affected by aging (Raz, 2000), and direct evidence of differential recruitment of frontal structures during conflict resolution in aging have been reported using the Stroop task (e.g., Milham et al., 2002). These same areas are recruited during meditation, and are thought to reflect cognitive control and attentional monitoring during the practice (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Hasenkamp et al., 2012; Sperduti, Martinelli, & Piolino, 2012; Tomasino et al., 2012). Moreover, long-lasting structural changes of gray and white matter in prefrontal regions have been associated with long as well as short-term meditation practice (Lazar et al., 2005; Luders, Clark, Narr, & Toga, 2011; Tang et al., 2010; for a recent review see Debarnot, Sperduti, Di Rienzo, & Guillot, 2014). In addition, Luders, Cherbuin, Kurth, and Lauche (2015) showed recently, in a large sample, that the age-related gray matter atrophy in these structures is consistently reduced in meditators. Taken together, these findings suggest that meditation would recruit frontal brain regions subserving attentional control, and boost neuronal plasticity in these structures that could possibly play a protecting role against the effect of aging, and, in turn, on the related cognitive processes.

### Limitations and conclusion

An obvious limitation of the present study is that due to the cross-sectional approach no firm conclusions about the causal role of meditation on the observed effect could be made. Indeed, other factors such as the life-style could have a positive potential impact in preserving from the age-related cognitive decline. This is a common limitation of most of the previous studies on the effect of meditation employing expert meditators, and in general of all studies investigating expertise. This limitation could be also addressed to most of the studies investigating the effect of short-term meditation interventions, since often they did not include an active control intervention. Another limitation is certainly the small sample size that makes difficult the generalization of our results to the general population. Thus, in future studies an effort should be made in employing longitudinal controlled trials in larger samples, including well-matched control interventions such as the recently validated Health Enhancement Program (HEP; MacCoon et al., 2012).

In conclusion, we showed that the efficiency of the executive attentional network was specifically reduced in healthy elderly, and that, on the contrary, age-matched long-term meditators did not show this effect: their performance was even comparable to that of young adults. These findings are encouraging for the investigation of the potential beneficial impact of meditation in elderly on other cognitive processes that are attained in this population such as memory. Moreover, our results could inform geriatric health-care prevention and intervention strategies, proposing a new tool for cognitive remediation in elderly populations.

## Acknowledgements

We would like to thank Ariane Cartigny, Mariam Coulibaly, Clémence Gardette, Samira Chagar, Kaël Lauwaert, and Elsa Cenier, Master's students at the University Paris Descartes for their help in collecting data. The following meditation centers: Zen Paris, Forum 104, La Maison de l'Inspir, Dana Sangha Paris, Rimay – Sangha Loka Paris for their collaboration. We greatly thank all the participants that took part in the study.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## References

- Aschenbrenner, A. J., & Balota, D. A. (2015). Interactive effects of working memory and trial history on stroop interference in cognitively healthy aging. *Psychology and Aging, 30*, 1–8. doi:10.1037/pag0000012
- Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the National Academy of Sciences, 104*, 11483–11488. doi:10.1073/pnas.0606552104
- Chan, D., & Woollacott, M. (2007). Effects of level of meditation experience on attentional focus: Is the efficiency of executive or orientation networks improved? *The Journal of Alternative and Complementary Medicine, 13*, 651–658. doi:10.1089/acm.2007.7022
- Cieslik, E. C., Mueller, V. I., Eickhoff, C. R., Langner, R., & Eickhoff, S. B. (2015). Three key regions for supervisory attentional control: Evidence from neuroimaging meta-analyses. *Neuroscience & Biobehavioral Reviews, 48*, 22–34. doi:10.1016/j.neubiorev.2014.11.003
- Debartot, U., Sperduti, M., Di Rienzo, F., & Guillot, A. (2014). Experts bodies, experts minds: How physical and mental training shape the brain. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00280
- Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *Neuroimage, 26*, 471–479. doi:10.1016/j.neuroimage.2005.02.004
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347. doi:10.1162/089892902317361886
- Fernandez-Duque, D., & Black, S. E. (2006). Attentional networks in normal aging and Alzheimer's disease. *Neuropsychology, 20*, 133–143. doi:10.1037/0894-4105.20.2.133
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198. doi:10.1016/0022-3956(75)90026-6
- Fossella, J., Posner, M. I., Fan, J., Swanson, J. M., & Pfaff, D. W. (2002). Attentional phenotypes for the analysis of higher mental function. *The Scientific World Journal, 2*, 217–223. doi:10.1100/tsw.2002.93
- Fox, K. C. R., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., & Christoff, K. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience & Biobehavioral Reviews, 43*, 48–73. doi:10.1016/j.neubiorev.2014.03.016
- Gard, T., Hölzel, B. K., & Lazar, S. W. (2014). The potential effects of meditation on age-related cognitive decline: A systematic review. *Annals of the New York Academy of Sciences, 1307*, 89–103. doi:10.1111/nyas.2014.1307.issue-1
- Gazzaley, A., & D'esposito, M. A. R. K. (2007). Top-down modulation and normal aging. *Annals of the New York Academy of Sciences, 1097*, 67–83. doi:10.1196/annals.1379.010

- Gruber, E., Buschke, H., Crystal, H., Bang, S., & Dresner, R. (1988). Screening for dementia by memory testing. *Neurology*, *38*, 900–900. doi:10.1212/WNL.38.6.900
- Hasenkamp, W., Wilson-Mendenhall, C. D., Duncan, E., & Barsalou, L. W. (2012). Mind wandering and attention during focused meditation: A fine-grained temporal analysis of fluctuating cognitive states. *Neuroimage*, *59*, 750–760. doi:10.1016/j.neuroimage.2011.07.008
- Hasher, L., Lustig, C., & Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. *Variation in Working Memory*, *19*, 227–249.
- Hawkes, T. D., Manselle, W., & Woollacott, M. H. (2014). Cross-sectional comparison of executive attention function in normally aging long-term T'ai Chi, meditation, and aerobic fitness practitioners versus sedentary adults. *The Journal of Alternative and Complementary Medicine*, *20*, 178–184. doi:10.1089/acm.2013.0266
- Jennings, J. M., Dagenbach, D., Engle, C. M., & Funke, L. J. (2007). Age-related changes and the attention network task: An examination of alerting, orienting, and executive function. *Aging, Neuropsychology, and Cognition*, *14*, 353–369. doi:10.1080/13825580600788837
- Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioral Neuroscience*, *7*, 109–119. doi:10.3758/CABN.7.2.109
- Kalafat, M., Hugonot-Diener, L., & Poitrenaud, J. (2003). Standardisation et étalonnage français du “mini mental state”(MMS) version GRECO. *Revue De Neuropsychologie*, *13*, 209–236.
- Lazar, S. W., Kerr, C. E., Wasserman, R. H., Gray, J. R., Greve, D. N., Treadway, M. T., & Fischl, B. (2005). Meditation experience is associated with increased cortical thickness. *Neuroreport*, *16*, 1893–1897. doi:10.1097/01.wnr.0000186598.66243.19
- Luders, E. (2014). Exploring age-related brain degeneration in meditation practitioners. *Annals of the New York Academy of Sciences*, *1307*, 82–88. doi:10.1111/nyas.2014.1307.issue-1
- Luders, E., Cherbuin, N., Kurth, F., & Lauche, R. (2015). Forever young (er): Potential age-defying effects of long-term meditation on gray matter atrophy. *Deutsche Zeitschrift für Akupunktur*, *58* (4), 30–31.
- Luders, E., Clark, K., Narr, K. L., & Toga, A. W. (2011). Enhanced brain connectivity in long-term meditation practitioners. *Neuroimage*, *57*, 1308–1316. doi:10.1016/j.neuroimage.2011.05.075
- Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences*, *12*, 163–169. doi:10.1016/j.tics.2008.01.005
- MacCoon, D. G., Imel, Z. E., Rosenkranz, M. A., Sheftel, J. G., Weng, H. Y., Sullivan, J. C., & Lutz, A. (2012). The validation of an active control intervention for mindfulness based stress reduction (MBSR). *Behaviour Research and Therapy*, *50*, 3–12. doi:10.1016/j.brat.2011.10.011
- Maciokas, J. B., & Crognale, M. A. (2003). Cognitive and attentional changes with age: Evidence from attentional blink deficits. *Experimental Aging Research*, *29*, 137–153. doi:10.1080/03610730303715
- Mahoney, J. R., Verghese, J., Goldin, Y., Lipton, R., & Holtzer, R. (2010). Alerting, orienting, and executive attention in older adults. *Journal of the International Neuropsychological Society*, *16*, 877–889. doi:10.1017/S1355617710000767
- Marciniak, R., Sheardova, K., Čermáková, P., Hudeček, D., Šumec, R., & Hort, J. (2014). Effect of meditation on cognitive functions in context of aging and neurodegenerative diseases. *Frontiers in Behavioral Neuroscience*, *8*. doi:10.3389/fnbeh.2014.00017
- Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: Insights from an fMRI study of the stroop task. *Brain and Cognition*, *49*, 277–296. doi:10.1006/brcg.2001.1501
- Nee, D. E., Wager, T. D., & Jonides, J. (2007). Interference resolution: Insights from a meta-analysis of neuroimaging tasks. *Cognitive, Affective, & Behavioral Neuroscience*, *7*, 1–17. doi:10.3758/CABN.7.1.1
- Pagnoni, G., & Celic, M. (2007). Age effects on gray matter volume and attentional performance in Zen meditation. *Neurobiology of Aging*, *28*, 1623–1627. doi:10.1016/j.neurobiolaging.2007.06.008
- Peirce, J. W. (2007). Psychopy-psychophysics software in python. *Journal of Neuroscience Methods*, *162*, 8–13. doi:10.1016/j.jneumeth.2006.11.017

- Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, 13, 25–42. doi:10.1146/annurev.ne.13.030190.000325
- Prakash, R., Rastogi, P., Dubey, I., Abhishek, P., Chaudhury, S., & Small, B. J. (2012). Long-term concentrative meditation and cognitive performance among older adults. *Aging, Neuropsychology, and Cognition*, 19, 479–494. doi:10.1080/13825585.2011.630932
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18, 849.
- Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates.
- Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS Biology*, 5, e138. doi:10.1371/journal.pbio.0050138
- Sperduti, M., Martinelli, P., & Piolino, P. (2012). A neurocognitive model of meditation based on activation likelihood estimation (ALE) meta-analysis. *Consciousness and Cognition*, 21, 269–276. doi:10.1016/j.concog.2011.09.019
- Tang, Y.-Y., Lu, Q., Geng, X., Stein, E. A., Yang, Y., & Posner, M. I. (2010). Short-term meditation induces white matter changes in the anterior cingulate. *Proceedings of the National Academy of Sciences*, 107, 15649–15652. doi:10.1073/pnas.1011043107
- Tang, Y.-Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., & Posner, M. I. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences*, 104, 17152–17156. doi:10.1073/pnas.0707678104
- Tang, Y.-Y., Posner, M. I., & Rothbart, M. K. (2014). Meditation improves self-regulation over the life span. *Annals of the New York Academy of Sciences*, 1307, 104–111. doi:10.1111/nyas.2014.1307.issue-1
- Tomasino, B., Fregona, S., Skrap, M., & Fabbro, F. (2012). Meditation-related activations are modulated by the practices needed to obtain it and by the expertise: An ALE meta-analysis study. *Frontiers Human Neuroscience*, 6, 10–3389.
- van den Hurk, P. A. M., Giommi, F., Gielen, S. C., Speckens, A. E. M., & Barendregt, H. P. (2010). Greater efficiency in attentional processing related to mindfulness meditation. *The Quarterly Journal of Experimental Psychology*, 63, 1168–1180. doi:10.1080/17470210903249365
- van Leeuwen, S., Müller, N. G., & Melloni, L. (2009). Age effects on attentional blink performance in meditation. *Consciousness and Cognition*, 18, 593–599. doi:10.1016/j.concog.2009.05.001
- Zhou, S.-S., Fan, J., Lee, T. M. C., Wang, C.-Q., & Wang, K. (2011). Age-related differences in attentional networks of alerting and executive control in young, middle-aged, and older Chinese adults. *Brain and Cognition*, 75, 205–210. doi:10.1016/j.bandc.2010.12.003
- Zhu, D. C., Zacks, R. T., & Slade, J. M. (2010). Brain activation during interference resolution in young and older adults: An fMRI study. *Neuroimage*, 50, 810–817. doi:10.1016/j.neuroimage.2009.12.087