



OPEN Examining cognitive differences in expert meditators and non-meditators older adults

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With aging, slight changes in some cognitive processes can be observed. Therefore, we aimed to assess if meditation expertise is associated with preserved cognition in key domains affected in aging. We used data from two older-adult samples of the Medit-Ageing Age-well Study: 135 non-meditators and 27 expert meditators. We examined group differences in four objective cognitive domains (attention, executive functioning, episodic memory, and global cognition) and three subjective scores: Cognitive Difficulties Scale (CDS) total score as well as Attentional Style Questionnaire (ASQ) internal and external scores using generalized mixed effect models, controlling for age, sex, and education. We did not observe group differences on attentional, executive and global cognitive scores or on ASQ internal score and CDS total score. However, meditators reported less external distraction (ASQ external score) and had better memory than non-meditators. These cross-sectional results indicate a better management of external stimuli and higher memory performance in expert meditators. Memory difficulties and distractions being the main complaints of older people, prolonged meditation practice could lead them to greater cognitive capacities important for healthy aging.

Trial registration: NCT02977819 (ClinicalTrials.gov)

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Maintaining cognitive and mental health in aging is a major challenge, even in the absence of pathological conditions. Regarding cognition, slight declines in memory, attention, and executive functioning are frequently observed on cognitive tasks¹. Moreover, older adults often report memory difficulties and distractions in their daily life^{2,3}. However, there is variability in the profiles of cognitive changes of healthy older people due to a series of genetic, biological and environmental factors⁴. According to the revised Scaffolding Theory of Aging and Cognition (STAC-r⁵), non-pharmacological interventions, such as exercise, new learning, social/intellectual engagement, cognitive training, and meditation training, can confer cognitive benefits.

Indeed, some evidence indicates that meditation may prevent age-related cognitive decline^{6,7}. In a recent meta-analysis, Whitfield et al.⁸ observed that, in people over 60 years old, mindfulness meditation (MM) interventions of at least four weeks led to a small improvement in executive functions compared to control groups. This positive effect could be explained by training of attention regulation (e.g., resistance to distracting information), a main component of mindfulness practices^{9–12}. However, other practices such as loving-kindness and compassion meditation (LKCM) could also positively impact cognition by acting on positive emotional schemes, as we know that emotions and cognitive performance may be correlated^{13–15}. A mechanistic model

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was proposed to explain how meditation practice, which comprises both MM and LKCM, could promote cognition, mental health, and well-being by strengthening attention control, metacognitive monitoring, emotion regulation and pro-social capacities¹⁶. One way to explore the plausibility of this proposal consists of comparing the cognition of older adult long-term meditators with many years of practice to non-meditators.

In the existing literature on this topic, better selective attention and greater flexibility regarding the engagement and the disengagement of attention toward stimuli was noticed in long-term meditators compared with non-meditators matched for age, sex and sociocultural level¹⁷. Moreover, other authors have also shown higher cognitive abilities with advanced meditation practice on a sustained attention task¹⁸. They also observed a positive effect of practice on gray matter volume in the putamen, a brain structure involved in attentional functioning. Other studies also noted better attentional and executive processes in long-term meditators compared to non-meditators^{7,19,20}. However, Kral et al.²¹ observed no difference between long-term and non-meditator groups on the alerting, orienting and executive attentional processes involved in the Attention Network Task (ANT²²) administered in a functional magnetic resonance imaging scanner. Moreover, Lykins et al.²³ also did not report differences between long-term meditators and non-meditators regarding attentional or executive processes (sustained attention, attention switching, and inhibition), but they did underline a higher performance on tasks assessing short- and long-term memory. Some studies also investigated the association of long-term practice of meditation on changes in the subjective assessment of cognitive functioning. For example, meditators have reported higher attentional capacities than meditation-naïve participants on the attentional subscale of Emotional Styles Questionnaire²¹. Alongside this result, advanced meditation practice was associated with a higher interoception (with a trend for higher exteroception) but there was no difference regarding the score on the Levels of Emotional Awareness scale between expert and non-expert adults²⁴. However, to our knowledge, only one study included adults with a mean age over 60 years old⁷. Moreover, a limited number of cognitive tasks was used in most studies which preclude generalizability of the results. Therefore, the assumption of a positive effect of sustained meditation practice on cognitive functioning in aging needs further investigation.

In the present study, we explored the hypothesis of a protective effect of long-term meditation practice on cognition of older adults by comparing subjective (questionnaires about perception of cognitive functioning [the Cognitive Difficulties Scale, CDS²⁵ and about distractions' management [the Attentional Scale Questionnaire, ASQ, assessing sensitivity to internal and external distraction²⁶) and objective (composite task-related scores in the attentional, executive, memory and global cognition domains) baseline data from the Age-Well clinical trial on expert meditators (reported having at least 10,000 h of MM and LKCM practice) and non-meditator participants. Unlike previous studies, we performed a thorough cognitive assessment in participants over 60 years old. In previous longitudinal analyses of the dataset, we observed that an 18-month meditation training (comprising mindfulness and compassion practice) had an impact on management of external distractors compared to pursuing daily life activities or following an 18-month non-native language training²⁷. However, we did not find an effect of the meditation intervention on other subjective reports of cognition (management of internal distractors and cognitive complaints) or on objective cognition (attention, executive functions, memory and global cognition). We aimed here to investigate whether expertise in meditation could lead to divergent results compared to those found among individuals undergoing a meditation intervention for 18 months. We hypothesized that the expert meditators would perform better on attention and executive tasks (according to the only article on old expert meditators⁷). Meditation could also, to a lower extent, improve memory and global cognition as well as diminish perception of cognitive difficulties and sensitivity to internal and external interference (based on results from adult expert meditators^{21,24}).

Results

Groups demographics and differences

There was a difference between non-meditators and experts on education ($U = 2825.50$, $p = 0.005$) and sex (Chi-Square = 5.50, $p = 0.02$), with the experts being more educated and composed of proportionally more men than women. However, there was no difference regarding age ($U = 2527.00$, $p = 0.14$) (Table 1).

Regarding cardiovascular risk (FRS²⁸), APOE genotype, brain amyloid load, anxiety (STAI B²⁹), and depression (GDS³⁰), there was no difference between groups ($p > 0.05$). However, there was a group difference regarding the meditation subjective scores³¹ with the expert meditators having higher attentional ($U = 3134.00$, $p < 0.0001$), constructive ($U = 2992.00$, $p < 0.001$) and deconstructive ($U = 3323.50$, $p < 0.0001$) self-reported capacities (Table 1).

Core models

Generalized mixed effect models were employed with groups as predictors, and age, education and sex as covariates. Regarding subjective cognition, we did not observe a difference between groups on the CDS total score (estimate: 1.61, 95% CI = [-5.18, 8.40]) and ASQ internal score (estimate: -0.89, 95% CI = [-2.92, 1.14]) between experts and non-meditators (all $p_{\text{FDR}}^s > 0.52$). However, we found a difference on the ASQ external (Table 2; Fig. 1) with experts reporting a better ability to manage external distraction than non-meditators (estimate: -2.86, 95% CI = [-4.82, -0.90], $p_{\text{FDR}} = 0.015$, $R^2_{\text{sp}} = 0.05$).

Regarding objective cognition, no differences were observed between the expert and meditation-naïve groups on attention (estimate: -0.01, 95% CI = [-0.41, 0.39]), executive functioning (estimate: 0.30, 95% CI = [-0.09, 0.70]) or global cognition (estimate: 0.17, 95% CI = [-0.22, 0.56]); all $p_{\text{FDR}}^s > 0.22$). However, we observed a group effect on episodic memory (estimate: 0.57, 95% CI = [0.17, 0.97], $p_{\text{FDR}} = 0.017$, $R^2_{\text{sp}} = 0.05$) with expert meditators having a better memory performance than non-meditators (Table 3; Fig. 2).

Variables of interest	Experts (N = 27)	Non-meditators (N = 135)	Statistic	P
Age, Mean \pm SD	70.19 \pm 4.89	68.80 \pm 3.80	U = 2527.00	0.14
Education, Mean \pm SD	15.19 \pm 3.33	13.16 \pm 3.09	U = 2825.50	< 0.01
Sex (female), n (%)	10 (37%)	83 (61.48%)	Chi ² = 5.50	0.02
Amyloid, Mean \pm SD	1.21 \pm 1.13 ¹	1.26 \pm 1.16 ³	U = 2040.00	0.63
APOE (e4 positive), n (%)	6 (22%)	13 (29%)	Chi ² = 2.02	0.16
Framingham Risk Score, Mean \pm SD	19.38 \pm 13.85 ²	19.34 \pm 12.72 ³	U = 2386.00	0.34
Practice (number of hours of life-long meditation practice), Mean \pm SD	31,881.86 \pm 30,032.6	/	/	/
Attentional meditative composite score, Mean \pm SD	0.82 \pm 0.71 ²	-0.16 \pm 0.97	U = 2959.00	< 0.0001
Constructive meditative composite score, Mean \pm SD	0.77 \pm 1.19	-0.15 \pm 0.89	U = 2853.00	< 0.01
Deconstructive meditative composite score, Mean \pm SD	0.91 \pm 0.95	-0.18 \pm 0.91	U = 3157.00	< 0.0001
STAI B (total score), Mean \pm SD	32.22 8.27	34.58 7.00	U = 1844.50	0.11
GDS (total score), Mean \pm SD	1.22 \pm 1.25	1.28 \pm 1.74	U = 2290.00	0.67
GDS (categorical score), n (%) of people with depressive symptoms	17/27 (63%)	77/135 (57%)	Chi ² = 0.32	0.57

Table 1. Demographic data. *Note.* SD: Standard Deviation, Amyloid: brain amyloid load (standard uptake value ratios were acquired with late Florbetapir-PET), APOE: Apolipoprotein E, STAI B: State-Trait Anxiety Inventory (trait version), GDS: Geriatric Depression Scale (for the categorical score, there were 2 groups: people with no depressive symptoms had a score of 0 and people with depressive symptoms had a score > 0), ¹n = 24, ²n = 26, ³n = 134, **group differences in bold.**

Predictors	Estimate (95% CI)	F (df)	P _{FDR}
(A) CDS total score			
Group (experts vs non-meditators)	1.61 (-5.18, 8.40)	0.22 (1, 157)	0.78
Education	-0.85 (-1.65, -0.05)	4.35 (1, 157)	0.08
Age	0.11 (-0.51, 0.72)	0.12 (1, 157)	0.79
Sex (female vs male)	-1.24 (-6.36, 3.87)	0.23 (1,157)	0.78
(B) ASQ internal score			
Group (experts vs non-meditators)	-0.89 (-2.92, 1.14)	0.75 (1,154)	0.52
Education	-0.32 (-0.56, -0.08)	6.8 (1,154)	0.025 (R²_{sp} = 0.04)
Age	-0.18 (-0.37, -0.002)	3.97 (1,154)	0.09
Sex (female vs male)	0.32 (-1.20, 1.84)	0.18 (1,154)	0.79
(C) ASQ external score			
Group (experts vs non-meditators)	-2.86 (-4.82, -0.90)	8.34 (1,154)	0.015 (R²_{sp} = 0.05)
Education	-0.18 (-0.41, 0.06)	2.24 (1,154)	0.22
Age	-0.02 (-0.19, 0.16)	0.04 (1,154)	0.87
Sex (female vs male)	-0.27 (-1.73, 1.20)	0.13 (1,154)	0.79

Table 2. Core models on subjective cognition. *Note.* CI: Confidence Interval, df: degrees of freedom, R²_{sp}: semi-partial R², ASQ: Attentional Style Questionnaire, CDS: Cognitive Difficulties Scale, FDR: False Discovery Rate, **significant effects in bold.**

Exploratory analyses

When we added cognitive risk factors (amyloid, APOE and FRS) to the core models, results regarding group effect remained substantively unchanged. Anxiety and depression were also used as covariates on the core models with ASQ external and memory, and the group-effect for both scores remained significant. (*Supplemental Table S1*).

Self-reported meditation capacities were also added as covariates on the core models with ASQ external and memory scores. When the meditation capacities were used as covariates in the model with ASQ external score, the group effect disappeared. Moreover, only a trend of deconstructive capacity effect was observed on memory score and the group effect appeared to be a trend as well (*Supplemental Table S2*).

Finally, we found a positive association between formal practice and memory performance in the expert group. However, we did not observe such a link between practice and ASQ external score (*Supplemental Table S3*).

Discussion

This study aimed to investigate the difference between older adults who were expert meditators and older non-mediator adults regarding subjective cognition (perceived attentional style and cognitive difficulties) and objective performance in different cognitive domains (attention, executive functions, episodic memory, and global cognition). Contrary to our hypotheses, we did not observe a group difference in subjective cognitive

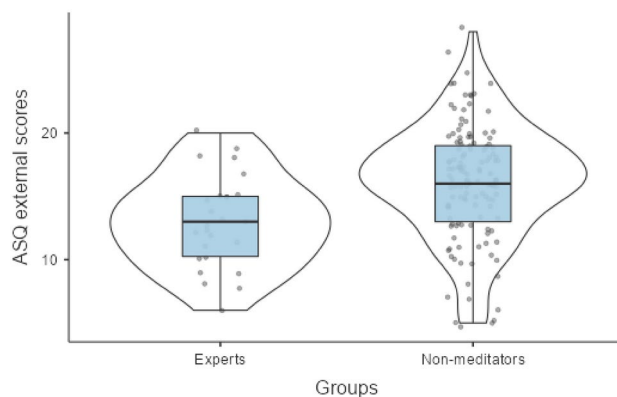


Fig. 1. Group-difference (experts and non-meditators) on the Attentional Style Questionnaire (ASQ) external score.

Predictors	Estimate (95% CI)	F (df)	P _{FDR}
(A) Attentional composite score			
Group (experts vs non-meditators)	−0.01 (−0.41, 0.39)	0.00 (1, 157)	0.97
Education	0.05 (0.001, 0.10)	4.04 (1, 157)	0.09
Age	−0.10 (−0.13, −0.06)	28.54 (1, 157)	0.0004 ($R^2_{sp} = 0.15$)
Sex (female vs male)	0.19 (−0.11, 0.49)	1.54 (1,157)	0.32
(B) Executive function composite score			
Group (experts vs non-meditators)	0.30 (−0.09, 0.70)	2.27 (1, 157)	0.22
Education	0.09 (0.05, 0.14)	15.87 (1, 157)	0.0004 ($R^2_{sp} = 0.09$)
Age	−0.07 (−0.11, −0.04)	16.62 (1, 157)	0.0004 ($R^2_{sp} = 0.10$)
Sex (female vs male)	0.32 (0.03, 0.62)	4.61 (1, 157)	0.08
(C) Episodic memory composite score			
Group (experts vs non-meditators)	0.57 (0.17, 0.97)	8.01 (1, 156)	0.017 ($R^2_{sp} = 0.05$)
Education	0.03 (−0.01, 0.08)	2.00 (1, 156)	0.25
Age	−0.05 (−0.09, −0.01)	7.71 (1, 156)	0.017 ($R^2_{sp} = 0.05$)
Sex (female vs male)	0.81 (0.51, 1.11)	28.73 (1,156)	0.0004 ($R^2_{sp} = 0.16$)
(D) PACC5			
Group (experts vs non-meditators)	0.17 (−0.22, 0.56)	0.73 (1, 156)	0.52
Education	0.09 (0.04, 0.14)	15.37 (1, 156)	0.0004 ($R^2_{sp} = 0.09$)
Age	−0.08 (−0.11, −0.04)	20.44 (1, 156)	0.0004 ($R^2_{sp} = 0.12$)
Sex (female vs male)	0.64 (0.35, 0.93)	18.73 (1, 156)	0.0004 ($R^2_{sp} = 0.11$)

Table 3. Core models on objective cognition. *Note.* CI: Confidence Interval, df: degrees of freedom, R^2_{sp} : semi-partial R^2 , FDR: False Discovery Rate, **significant effects in bold**.

difficulties or on the management of internal stimuli. There was insufficient evidence to conclude for a significant difference between groups regarding objective global, attentional, or executive cognitive function. However, we found that meditation experts were less distracted by external stimuli (such as noise or movement) and outperformed non-meditators on a composite score of episodic memory.

While we did not observe a group difference on the management of internal stimuli such as thoughts, we found that expert meditators reported being better able to deal with external distractions. A better management of external stimuli after meditative training is compatible with the attentional control and metacognitive processes that are typically developed during meditation¹⁶. A difference between long-term meditators and non-meditators over 60 years old in the management of external distraction during cognitive performance was also observed in a previous study⁷. The authors explored resistance to interference using task-related distractions and observed that meditators are less distracted by incongruent stimuli than non-meditators⁷. However, the use of cross-sectional designs does not allow to infer a causal link between meditation practice and improved performance. Interestingly, we also observed a better management of external distraction (again together with no evidence to support an effect regarding internal distraction susceptibility) in older participants who underwent an 18-month meditation intervention²⁷. Taken as a whole, these results are compatible with the proposal of a positive effect of meditation practice on attentional performance when assessed with self-report. A better ability to deal with distraction is particularly interesting because a consequence of aging seems to be an increase in

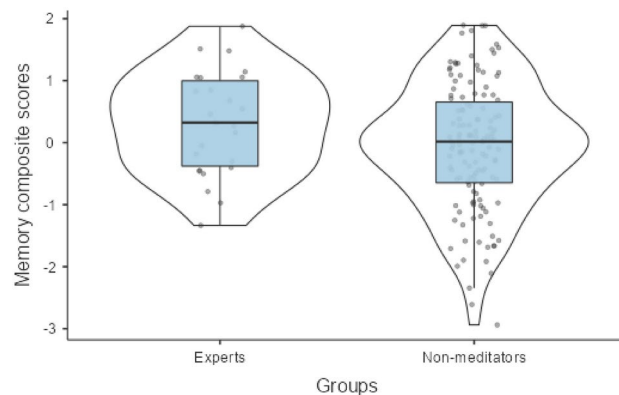


Fig. 2. Group-difference (experts and non-meditators) on the memory composite score.

susceptibility to external distraction, especially for unrelated task distractors^{32,33}. In contrast, we did not observe beneficial effect of the 18-month meditation intervention on management of internal stimuli²⁷. We interpreted this finding by hypothesizing that older adults would have better emotional regulation³⁴ and therefore this capacity would not need to be enhanced contrary to external stimuli management. Indeed, as suggested in the Theory of Positivity Effect³⁵, older adults tend to have a more positive outlook on life and are less disturbed by negative thoughts. This interpretation may also explain the absence of evidence to conclude for a difference between experts and meditation-naïve older adults we observed for management of internal distraction in the present study if both groups have high ability to manage negative thoughts due to their age. However, a decrease in intrusive thoughts is observed through aging in some studies and most of the studies on this topic showed lower affective reactivity to these intrusive thoughts among older people³⁶. Moreover, less mind-wandering was also frequently observed during aging^{36,37}. Therefore, the insufficient evidence to support a group difference on internal distraction management might also be explained by a low occurrence of such distraction, and a same interpretation may be proposed for the absence of significant results of the 18-month meditation intervention we previously observed²⁷. However, these results and their interpretation need confirmation with samples including experts in meditation and non-meditators from a larger age range.

We did not observe a group difference on attentional and executive scores, as well as on a global cognitive score, although some studies have reported that long-term practice of meditation is associated with higher performance in these domains^{7,17–20} (see²³ for no evidence towards a group difference). However, our control participants naïve to meditation practice were in very good physical and cognitive health, which could result in a low sensitivity to detect group difference. Indeed, their health status and generally active lifestyle may have protected against subtle changes in attentional and executive functions, leading their performance close to the ones in the expert meditators. Nevertheless, other explanations can be highlighted. First, better cognitive performance in experts could be more susceptible of being observed when the meditation aspect is clearly emphasized in the objective of the testing procedure, by asking them to act on a task like they would act during a meditative state (see for example³⁸ cited by²³). Second, the speed-accuracy trade-off might differ between meditators and non-meditators, with meditators favoring accuracy by slowing down their responses. In that case, the expert meditators might perform better on tasks only assessing performance (as in the memory composite score) and not on tasks having an element of timed response (as assessed in some tasks of the other composites, for example, measures of reaction time or providing as much as possible correct responses within a time limit).

We found that experts in meditation had better memory performance compared to non-meditators. A positive effect of meditation on memory was previously reported in the literature in young expert meditators^{23,39}. It is particularly interesting to underline the same results in an older population as memory is one of the first complaints reported in this age range. Again, due to the cross-sectional design of our study, it may not be directly inferred from the results that meditation practice may protect from cognitive decline usually observed in aging. In that sense, an 18-month intervention in an older population did not show improved performance by comparison with non-native language learning or no intervention²⁷. However, we observed here a positive association between practice and memory performance. This may be interpreted as a positive effect of meditation on cognition that would occur following extended practice only. However, specifically designed longitudinal studies on expert meditators are needed to confirm this interpretation as other factors related to lifestyle and habits of that population can potentially drive the observed association.

Furthermore, the presence of a joint effect on both memory and external distraction management seems particularly interesting. Indeed, in the general population, a relationship between the attention and memory domains was highlighted, with the capacity of not being distracted by irrelevant stimuli being particularly important for encoding and retrieval memory processes⁴⁰. Moreover, suppression of irrelevant stimuli is linked with anticorrelation between dorsal attention and default mode networks and has repercussions on working memory processes⁴¹. We could therefore hypothesize that meditation, as a distraction management training, can also have a transfer effect on memory processes in our expert population. Further studies and analyses are needed to determine if the positive association between long-term meditation practice and memory is relatively global or impact specific processes. As already stated, in our previous paper⁴², we did not evidence effect on

memory after an 18-month intervention among people that had never learned meditation before. That could reflect the importance of a longer training to see objective effects on cognition. Longitudinal studies among experts in meditation would be interesting to carry on in order to support this hypothesis.

In terms of exploratory analyses, we observed an association between the amount of practice and memory in the expert group composed of older adults, with more hours of practice associated with better performance. This is in line with our proposal that an 18-month intervention is not sufficient to observe a beneficial effect of meditation practice on memory performance⁴². Surprisingly, no association between practice score and the management of external distraction was observed. However, this is in agreement with authors that proposed that meditation (and more particularly mindfulness meditation) develops attention regulation in a continuous way^{10,43}. In the same vein, our 18-month intervention program also shows a positive effect on the management of external distraction²⁷. By integrating all these results from the Medit-Ageing research program, we suggest that management of external distraction is impacted by short and long-term practice of meditation, without evidence for a dose–response effect while a longer meditation practice would show benefits on objective memory. However, further studies are needed to investigate the effects of short, mid and long meditation training on cognition, and if there are different developmental trajectories for specific cognitive processes.

We may also highlight that the three meditative capacities (attentional, constructive, deconstructive) seem to influence the group effect in the models with memory or management of external stimuli since the group difference disappears when they are added in the model. Moreover, these analyses showed a relationship between deconstructive meditation capacity and the management of external distraction, independent from the group. The deconstructive capacity represents the ability to take distance from negative emotions, sensations or maladaptive cognitive schemes. We already reported an association between this capacity on global cognitive performance of older people naïve to meditation practice⁴⁴. Therefore, it seems that this deconstructive meditative capacity would be relevant to study along with the management of external perception and sensations.

This work highlights differences between meditators and non-meditators (in favor of meditators) on management of external distraction and episodic memory performance which are the main complaints among older people even before the report of objective cognitive decline^{2,3}. However, longitudinal studies are needed to confirm the positive effect of meditation practice on distraction and memory during aging. The study also has some limitations. First, although our sample size of experts in meditation is higher than in previous studies on older people^{7,45}, it remains relatively small and other studies with more expert meditators should be conducted. Second, the two groups are different in terms of demographics, with more males and higher education in experts, and also in sample size. Even if we did not find a link between education and memory performance or management of external stimuli, its potential influence must be considered regarding cognition. Indeed, previous studies have already demonstrated the benefit of a higher education on cognitive performance^{46,47}. Third, regarding the objective cognitive testing, the evaluators were not blind to the status of the participants (experts vs. non-meditators). Fourth, other lifespan aspects (i.e., leisure activities, social life, personality traits) than meditation practice may impact the results. Indeed, experts who regularly experience meditation retreats could be less confronted with diverse social situations (including family and work-related aspects) than non-meditators. In future studies, daily life activities and psychological characteristics measured by questionnaires would worth being considered, both for meditators and non-meditators participants. Finally, we may not reject a social desirability bias on self-reports for management of external stimuli among experts in meditation. Meditators could have rated themselves more positively on the scale as this effect is expected by practice. In agreement with that interpretation, we did not find a group difference in the task-related measure of executive attention. However, our executive composite score cannot be considered as a pure measure of sensitivity to interference. Therefore, future studies relating self-report for management of external distraction with tasks specifically designed to measure sensitivity to interference would be interesting to carry on among experts in meditation.

In conclusion, this study shows a greater management of external distraction and memory performance in experts in meditation compared to non-meditators, with the amount of practice positively associated with objective memory performance. However, further studies are needed to support these results, particularly about management of external distractions, which has not been extensively investigated in the literature. It would also be interesting to investigate the deconstructive aspects of meditation in depth. Indeed, most articles from now were interested in attentional aspects or did not distinguish between attentional and deconstructive capacities of mindfulness meditation⁴⁸. Although one recent protocol was published with the aim of investigating the impact of deconstructive meditation on well-being and self-deconstruction⁴⁹, to our knowledge, very little is yet known on its impact on attention regulation and memory. Finally, it will be interesting to better understand the relationships between the non-distracting capacities of meditation (linked with attentional processes) and memory processes in long-term meditators.

Method

Study design and participants

This study is composed of two different samples from the Age-well study of the Medit-Ageing project (see Table 1): a sample of non-meditators⁵⁰ and a sample of expert meditators⁵¹. The global protocol of the two studies was registered on ClinicalTrials.gov under the identifier NCT02977819. All participants gave their written informed consent to participate in the study and the research was completed in accordance with the declaration of Helsinki. The Age-Well clinical trial was approved by the ethics committee CPP (Comite de Protection des Personnes) Nord-Ouest III, Caen, France (EudraCT: 2016–002,441–36; IDRCB: 2016-A01767–44). For both samples, the participants had to be retired for at least one year and to have seven or more years of education. The exclusion criteria were a history of drug abuse or presence of neurological or psychiatric diseases. At the screening stage, participants were excluded if they had a score < 27 on the Mini Mental State Examination (MMSE⁵²), a score ≥ 7

on the Depression Montgomery and Asberg Depression Rating Scale (MADRS⁵³), a normalized score < -1.65 at the Wisconsin Card Sorting Test⁵⁴ and on the RL-RII⁵⁵, as well as a score $> 16/18$ at an English test (oral and written comprehension).

For the non-meditators' sample, data acquired before randomization in one of the three arms (meditation training, non-native language training and non-intervention) of the trial were analyzed. The sample is composed of 135 French-speaking cognitively unimpaired older non-meditator adults (aged between 65 and 84 years old).

For the meditation experts' sample, after a first screening, participants (also aged from 65 and 84 years old) had only one assessment. During this session, behavioral, cognitive, biological and neuroimaging data were collected. Eligibility criteria included: practicing mindfulness and loving-kindness meditation for $\geq 10,000$ h and participating in a meditation retreat for at least six cumulative months. Further, they were required to also practice meditation on a daily basis (at least 6 days a week and at least 45 min per session). They also had more than seven years of education, had to be free of any neurological or psychiatric diseases, and completed the same screening tests as the non-meditators (with the exception of the English test). For experts who were not fluent in French, cognitive testing was conducted in their usual language (English or Dutch) by native speakers. Evaluators were not blind to the fact these participants were expert meditators. The total sample was composed of 27 cognitively unimpaired expert meditators.

Cognitive assessment

Regarding subjective cognition, we used the raw data of the Cognitive Difficulties Scale and the Attentional Style Questionnaire.

The Cognitive Difficulties Scale (CDS) is a 39-item scale that assesses cognitive complaints of older people²⁵. The questionnaire evaluated memory, attention, language, spatiotemporal orientation and praxis domains. The modalities are examined on a 5-point Likert scale ranging from 0 ("never") to 4 ("very often"). The items are summed to create a total score, with greater values representing more cognitive difficulties.

The Attentional Style Questionnaire (ASQ) assesses the level of sensitivity to distraction and is composed of two sub-scales: an internal score (e.g., distraction to thoughts) and an external score (e.g., distraction to noise, movements)²⁶. The questionnaire is composed of 12 items (7 for internal subscale and 5 for external subscale) which can be gathered in a total score (sum of all items). Each question is answered on a 5-point Likert scale (1 corresponding to "totally disagree" and 6 to "totally agree"). For the total and the subscales, higher scores represent more distraction to stimuli.

Regarding objective cognition, four cognitive composite scores were created: attentional, executive, episodic memory, and global cognition. For all composites, each cognitive test was standardized based on the mean and the standard deviation of the whole sample (experts and non-meditators). Then the standardized scores were averaged and were re-standardized with the standard deviation of the total sample⁴².

Attentional composite score was composed of Digit Span test forward (raw score⁵⁶), part A of Trail Making Test (TMT⁵⁷), Stroop naming⁵⁷, and WAIS-IV Coding (raw score⁵⁶).

Executive composite score contained Digit Span test backward (raw score⁵⁶), TMT part B (response time⁵⁷), Stroop interference (response time⁵⁷ and letter fluency (raw score⁵⁷).

Episodic memory composite score consisted of three scores from the California Verbal Learning Test-II (CVLT-II; sum of trials 1–5, immediate free recall, and delayed free recall⁵⁸), and two scores from the Logical Memory test (immediate recall and delayed recall⁵⁶).

Preclinical Alzheimer Cognitive Composite—5 (PACC5) was created with delayed free recall at the California Verbal Learning Test-II and Logical Memory, raw score at the Coding subtest from WAIS-IV, category fluency (raw score⁵⁷), and Mattis Dementia Rating Scale-2 (total score⁵⁹). This score was known as sensitive to early Alzheimer Disease related changes⁶⁰.

The raw data of subjective cognition and the standardized data of the cognitive composite scores are presented in Table 4. The raw scores of the cognitive tests used in the composites can be retrieved in *Supplemental Table S4*.

Additional measures

Participants' characteristics and meditation-related variables were used in exploratory analyses. Among these variables, there were two biomarkers (brain amyloid standard uptake value ratios and apolipoprotein ϵ with two

Variables of interest	Experts (N = 27)	Non-meditators (N = 135)
	Mean \pm SD	Mean \pm SD
Attention composite	-0.08 \pm 1.03	0.02 \pm 1.00
Executive composite	0.26 \pm 0.89	-0.05 \pm 1.02
Memory composite	0.31 \pm 0.83 ¹	-0.07 \pm 1.02
PACC5 composite	0.07 \pm 0.96 ¹	-0.01 \pm 1.01
CDS Total score	34.07 \pm 18.21	33.74 \pm 15.06
ASQ: Internal score	18.73 \pm 4.76 ¹	20.57 \pm 4.65 ²
ASQ: External score	13.00 \pm 3.64 ¹	16.17 \pm 4.51 ²

Table 4. Descriptive statistics of variables of interest (Cognitive Difficulties Scale and Attentional Style Questionnaire: internal and external scores). *Note.* SD: Standard Deviation, ¹n = 26; ²n = 133, CDS: Cognitive Difficulties Scale, ASQ: Attentional Style Questionnaire (see supplemental material, Table 1 for raw score of cognitive tests used in the composites).

groups: $\epsilon 4$ positive and $\epsilon 4$ negative), one cardiovascular risk score (Framingham Risk Score or FRS)²⁸, meditative subjective scores (attentional, constructive and deconstructive families of meditation³¹), anxiety measured by the State-Trait Anxiety Inventory—Trait version or STAI B²⁹, depression assessed by the Geriatric Depression Scale or GDS³⁰, and practice score (number of hours of meditation practice self-rated by experts participants). For depression, a categorical score was also created (with a score of 0 corresponding to no depressive symptoms, and a score > 0 associated with some depressive symptoms). More details on these additional measures can be found in Supplemental data (*Appendix 1*).

Power analysis

To detect a medium effect size ($f = 0.25$) with a power of 0.80 and an alpha error probability of 0.05, we determined that a sample size of 128 participants would be necessary.

Statistical analyses

SAS 9.4. software was used to analyze the data⁶¹. We considered $p < 0.05$ as a significant threshold. Regarding the core models, a Benjamini-Hochberg False Discovery Rate (FDR) correction was applied to correct for multiple testing. Graphs were created with the Jamovi 2.3.21 software⁶².

Demographic analyses

Mann–Whitney tests (PROC NPAR1 WAY Wilcoxon) were used to compare age, education, amyloid, FRS, and meditative subjective scores between non-meditators and experts. Chi-square tests were employed to observe if there was a difference in sex and APOE between the two groups.

Core models

Generalized mixed effect models (PROC GLIMMIX), with participant-level random intercepts, were employed with groups (i.e., non-meditators and experts) as predictors, and age, education and sex as covariates. The variables of interest (i.e., dependent variables) were subjective cognition (Attentional Style Questionnaire and Cognitive Difficulties scale) and objective cognition (attentional, executive, episodic memory and PACC5 composite scores). Semi-partial R-square (R_{sp}^2) was reported when a significant result was observed.

Exploratory analyses

We performed exploratory analyses to see the effects of additional variables. First, we used our core models (with groups as predictors and demographics as covariates) but we added cognitive risk factors as covariates (amyloid, APOE, FRS) to determine if they could explain the potential group effect on cognition. Second, we used anxiety measured by the STAI B and depression assessed by the GDS in our model as covariates to see if subjective cognitive scores (and eventually objective ones) may be influenced by anxio-depressive level. Third, when there was a group effect, we added the subjective meditation scores (attentional, constructive, and deconstructive capacities) to determine (1) if the between-group effect was maintained and (2) meditation capacities that were linked to cognitive scores. Fourth, when an effect in favor of expert meditators was found, practice score (number of hours of MM and LKCM formal practice, including retreats) was added as a predictor of cognitive performance (controlled for demographics) only in the experts' group.

Data availability

The data underlying this report are made available on request following approval by the executive committee and a formal data sharing agreement (<https://silversantestudy.eu/2020/09/25/data-sharing>). The Material can be mobilized, under the conditions and modalities defined in the Medit-Ageing Charter by any research team belonging to an Academic institution, for carrying out a scientific research project relating to the scientific theme of mental health and well-being in older people. The Material may also be mobilized by non-academic third parties, under conditions, in particular financial, which will be established by separate agreement between Inserm and by the said third party. Data sharing policies described in the Medit-Ageing charter are in compliance with our ethics approval and guidelines from our funding body. Data contain potentially identifying or sensitive patient information. To request data, please contact the data access committee via the official project website (<https://silversantestudy.eu/2020/09/25/data-sharing>) or via the corresponding author (f.collette@uliege.be).

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Author contributions

F.R.: manuscript writing; statistical analysis; interpretation of data; and incorporation of manuscript feedback. H.M.: substantial contributions to the conception and design of the work; interpretation of data; revision of the manuscript for important intellectual content. H.D.K.: revision of the manuscript for important intellectual content. M.S.: revision of the manuscript for important intellectual content. G.P.: revision of the manuscript for important intellectual content. E.S.: revision of the manuscript for important intellectual content. N.L.M.: substantial contributions to the conception and design of the work; revision of the manuscript for important intellectual content. AL: substantial contributions to the conception and design of the work; interpretation of data; revision of the manuscript for important intellectual content. F.C.: substantial contributions to the conception and design of the work; interpretation of data; revision of the manuscript for important intellectual content. G.C. reported grants from Fondation Alzheimer, personal fees from Fondation Alzheimer, grants from Association France Alzheimer et maladies apparentées, grants from Fondation Vaincre Alzheimer, grants from Fondation Recherche Alzheimer, and grants from Fondation pour la Recherche Médicale outside the submitted work. E.S. reported grants from the Belgian Fund for Scientific Research (FRS-FNRS Belgium) and from Fondation Recherche Alzheimer outside of the submitted work. A.L. has received research support from Fondation d'entreprise MMA des Entrepreneurs du Futur. N.L.M. reported a grant from EU Joint Programme-Neurodegenerative Disease Research (JPND) grant funded by the UK Medical Research Council (MR/T046171/1) outside the submitted work. F.C. is supported by the F.R.S.-FNRS-Belgium.

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Additional information

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