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On ne ramènera jamais les manifestations de notre âme
aux propriétés brutes des appareils nerveux
pas plus qu'on ne comprendra de suaves mélodies
par les seules propriétés du bois ou
des cordes du violon nécessaires pour les exprimer.

Claude Bernard, *Lettres beaujolaises*

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Résumé

Si l'on essaye de concentrer notre attention sur un objet physique ou mental donné, on s'aperçoit vite qu'elle ne peut pas rester indéfiniment fixée sur l'objet en question mais se ré-oriente rapidement vers d'autres pensées ou sensations, un phénomène appelé dérive attentionnelle. Fait intéressant, les anciennes traditions de pratiques de méditation ont développé une grande variété de méthodes visant à développer la prise de conscience des épisodes de dérive attentionnelle et à entraîner l'esprit à rester concentré. Il est important de souligner que la connaissance du contenu de l'attention est une information qui est personnelle au sujet et qui ne peut être évaluée qu'à l'aide de méthode prennant en compte la perspective à la première personne. Au cours de ma thèse, j'ai étudié à la fois la dérive attentionnelle et les états de méditation dans un effort pour mieux comprendre ce qui se passe dans le cerveau quand quelqu'un médite. Quelle que soit la tradition de méditation, les dérives attentionnelles sont omniprésentes pendant la méditation. Ce sujet constitue donc un point de départ idéal pour l'étude de la méditation. Ce phénomène de dérive attentionnelle n'est pas unique à la méditation mais est présent dès qu'une personne se concentre sur une tâche à l'exclusion de toute autre. En utilisant un protocole nouveau, nous montrons que les épisodes de dérive attentionnelle sont accompagnés par une amplitude accrue des basses fréquences EEG 1-3Hz delta et 4-7Hz theta ainsi qu'une réduction du traitement sensoriel pré-attentif, comme le montre l'analyse de potentiels évoqués. Ces résultats indiquent que la dérive attentionnelle est associée à un niveau réduit de vigilance, similaire aux premiers stades de la somnolence. Ceci est cohérent avec certains textes bouddhistes sur la méditation, qui représentent la dérive attentionelle comme un état de sommeil par rapport aux périodes où l'esprit est concentré. Puis, nous avons réalisé une étude comparative de l'activité EEG au cours de la méditation pour tenter de déterminer l'origine des résultats divergents de la littérature. Nous avons enregistré l'activité spontanée EEG de 3 groupes de méditants de 3 différentes traditions de méditation et d'un groupe de non-méditants en utilisant le même protocole. Nous avons montré que tous les groupes de méditants avaient une amplitude de fréquence gamma 60-110Hz plus élevée par rapport aux contrôles pendant la méditation, indiquant peut-être des processus attentionnels différents chez les méditants. Aucune différence n'a été trouvée entre l'état mental contrôle et l'état méditatif chez les méditants, ce qui suggère que les modifications dues à la pratique longue de la méditation sont plus robustes que les effets de l'état mental de méditation par rapport à un état contrôle. Dans l'ensemble, notre étude souligne la nécessité de mieux définir ce que pourrait être le meilleur état de contrôle mental pour la méditation. Au cours de ce travail j'ai également exploré les méthodologies pour recueillir des informations subjectives pertinentes. Notre travail apporte de nouvelles perspectives pour l'étude la conscience humaine, mais la route reste longue avant que nous ne comprenions parfaitement les mécanismes sous-jacents de notre vie intérieure.

Mots-clés: dérive attentionnelle, méditation, attention, électroencéphalographie

Abstract

Trying to focus our attention on any given physical or mental object, we soon realize it cannot be kept indefinitely focused and soon drifts towards other thoughts or sensations, a phenomenon called mind wandering. Interestingly, ancient traditions of meditation practices have developed a large variety of methods aiming at developing the awareness of mind wandering episodes and training the mind to remain focused. It is important to point out that the knowledge of the focus of attention is a type of information that is private to the subject and that can only be assessed using methods that take into account first-person perspectives. During my thesis, I studied both the mind wandering and the meditation mental states in an effort to better understand what is happening in the brain when someone meditates. First, regardless of the meditation tradition, mind wandering is ever present during meditation and it seemed like an ideal starting point for studying meditation. It is also a phenomenon that is not unique to meditation and is present whenever a person attempts to focus. Using a novel EEG protocol, we show that mind wandering episodes are accompanied by increased amplitude at low frequencies in the delta (1-3Hz) and theta (4-7Hz) frequency bands as well as a reduction of pre-attentive sensory processing as shown by the analysis event-related potentials. These results indicate that mind wandering is associated with a lower vigilance level, resembling early stages of drowsiness. These results are consistent with some Buddhist texts on meditation, in which mind wandering is considered to be a state of relative sleep where the mind is not aware. Then, we realized a comparative study of EEG activity during meditation to attempt to sort out the origin of the divergent results found in the literature. We recorded the spontaneous EEG activity of 3 groups of meditators from 3 different meditation traditions in addition to a non-meditator group using the same protocol and equipment. We showed that all groups of meditators had higher 60-110Hz gamma amplitude when compared to the controls during meditation, possibly indicating different attentional processes in meditators. No differences were found between the mental control state and the meditative state in meditators, suggesting that we were observing trait rather than state effects of meditation. Overall, our study emphasizes the need to better define what could be the best control mental state for meditation. During this work, I also explored the methodologies allowing the collection of accurate subjective data. Our work brings new data in the field of consciousness, mind wandering and meditation study, but the road will be long before we fully understand the mechanisms underlying our inner life.

Keywords: mind wandering, meditation, attention, electroencephalography

Résumé substantiel en français

Cette thèse traite de deux états mentaux, la dérive de l'attention et la méditation, étudiés grâce à la technique d'électroencéphalographie (EEG). Les dérives de l'attention, ou dérives attentionnelles (DA) correspondent à ces moments où, alors que nous sommes concentrés sur une tâche, notre conscience nous échappe et nous commençons à suivre le cours de pensées qui ne sont pas en lien avec la tâche en cours. Par exemple, il vous est certainement déjà arrivé, alors que vous étiez en train de lire, de vous rendre compte que vos yeux sont arrivés en bas de la page, alors même que vous étiez en train de songer à votre prochaine soirée et que vous n'avez aucune idée du contenu des lignes parcourues. Ces "échappements de conscience" sont très fréquents et occuperaient même près de 50% de notre vie mentale.

Fait intéressant, les anciennes traditions de pratiques de méditation ont développé une grande variété de méthodes visant à développer la prise de conscience des épisodes de dérive attentionnelle et à entraîner l'esprit à rester concentré. Il est important de souligner que la connaissance du contenu de l'attention est une information qui est personnelle au sujet et qui ne peut être évaluée qu'à l'aide de méthode prennant en compte la perspective à la première personne. Au cours de ma thèse, j'ai étudié à la fois la dérive attentionnelle et les états de méditation dans un effort pour mieux comprendre ce qui se passe dans le cerveau quand quelqu'un médite. Quelle que soit la tradition de méditation, les dérives attentionnelles sont omniprésentes pendant la méditation. Ce sujet constitue donc un point de départ idéal pour l'étude de la méditation. Comme évoqué précédemment, le phénomène de dérive attentionnelle n'est pas unique à la méditation mais est présent dès qu'une personne se concentre sur une tâche à l'exclusion de toute autre. L'entraînement à la méditation requiert la reconnaissance des dérives attentionnelles et la redirection de l'attention sur la tâche méditative après une DA. Les différentes traditions de méditations (il en existe des centaines) ont développé une grande variété de méthodes pour développer la prise de conscience des dérives attentionnelles et rester concentré. De fait, l'esprit sujet aux DA est considéré dans les textes bouddhiques comme étant "endormi" alors que l'esprit dépourvu de DA serait "clair, lucide". Par ailleurs, de nombreuses études récentes suggèrent un lien entre la pratique de la méditation et le bien-être physique et mental ainsi que des modifications des processus attentionnels et émotionnels. Certaines formes de méditation ont même été adaptées pour intégrer des pratiques thérapeutiques dans le traitement du stress et des angoisses par exemple. Que peut donc être les différences entre l'activité du cerveau d'une personne normalement sujette aux dérives attentionnelles et celui de celle qui s'est entraînée à la méditation ? C'est à cette question que cette thèse tente d'apporter des éléments de réponse, sous l'angle des indications données par l'activité neuronale enregistrée grâce à l'EEG. Parmi les techniques d'imagerie cérébrale, l'EEG présente l'avantage de permettre l'observation directe de la dynamique cérébrale. L'EEG permet en effet d'enregistrer à la surface du scalp le champ électrique produit par la somme des activités synchronisées, excitatrices ou inhibitrices, de grandes populations de neurones corticaux, donnant un aperçu des activités neuronales globales du cortex . L'EEG possède une excellente résolution temporelle, de l'ordre de la milliseconde. Ceci donne la possibilité d'analyser l'activité oscillatoire cérébrale, et fait de l'EEG une technique de choix pour l'étude de phénomènes cérébraux dynamiques.

Il est bon tout d'abord de rappeler que l'étude scientifique des états mentaux s'est depuis toujours heurtée aux difficultés posées par les données concernant l'expérience subjective, dont le recueil ne peut se faire que via un processus d'introspection du sujet. Ces données introspectives dont l'intégration dans des études scientifiques date du début du siècle dernier ont régulièrement été montrées du doigt comme n'étant pas fiables, le sujet pouvant ne pas être lui-même conscient des opérations se tenant dans son esprit. Fort heureusement, et notamment depuis les années 1990, les progrès faits dans le développement des techniques d'enregistrement et d'analyse des activités cérébrales permettent aujourd'hui de corréler les données introspectives avec des données physiologiques, apportant la touche d'objectivité initialement absente des études sur la conscience et relançant du même fait l'intérêt des neurosciences pour ce thème.

Nous avons tout d'abord réalisé une première étude visant à caractériser la dynamique des activités cérébrales lors des dérives attentionnelles. Les études en électroencéphalographie portant directement sur la dérive attentionnelle sont rares et utilisent principalement l'analyse des potentiels évoqués (PE). Toutefois l'étude des PEs ne permet pas une analyse complète des données contenues dans les EEG enregistrés. En effet, la dynamique oscillatoire de l'EEG est perdue lors du moyennage nécessaire au calcul des PEs. Les études existantes ne caractérisent donc que d'une façon limitée la dynamique de l'activité neuronale lors de la dérive attentionnelle.

Les dérives attentionnelles ainsi que nous l'avons déjà évoqué avec l'exemple de la lecture, peuvent se produire en l'absence initiale de prise de conscience du sujet qu'il n'est plus concentré sur sa tâche et est entré en état de dérive attentionnelle. Cette caractéristique met en évidence l'existence de processus de re-représentation des contenus de la conscience, temporellement dissociés de l'arrivée d'un contenu mental en conscience. et nous permettant l'accès aux contenus conscients en cours. Cet état de fait pose un problème lors de l'étude expérimentale des dérives attentionnelles: comment étudier un phénomène purement psychique qui peut se produire en l'absence de conscience explicite de la part du sujet ?

Une approche populaire, l' "échantillonage de l'experience" (experience sampling) consiste à interrompre régulièrement le sujet au cours de sa tâche pour lui demander d'indiquer où se trouvait son attention juste avant l'interruption: était il concentré sur l'exécution de la tâche ou bien était il perdu dans ses pensées, en état de DA ? Cependant, nous souhaitions pouvoir enregistrer l'activité cérébrale lors du rapport spontané de l'occurrence d'une DA par le sujet. En effet, c'est ce qu'il se passe lors de la méditation, le sujet doit se rendre compte par lui-même de la présence d'une dérive attentionnelle. Pour ce faire, nous avons mis au point un protocole nouveau, nous permettant de recueillir des indications sur l'occurrence d'une dérive attentionnelle basées sur le seul jugement introspectif du sujet: le sujet devait compter ses respirations en boucle, de 1 à 10, et presser un bouton chaque fois qu'il s'apercevait qu'il avait cessé de compter ou qu'il s'était perdu dans le compte de ses respirations. En parallèle de cette tâche, le sujet écoutait passivement un protocole de stimulus auditifs déviants, c'est à dire une succession de sons de basse fréquence tous identiques, interrompue aléatoirement et peu fréquemment par la présentation d'un son plus aigu. Un changement inattendu dans le cours d'une stimulation auditive, tel que dans le protocole de stimulus déviant, provoque une activité cérébrale spécifique en réponse à la détection de ce changement et nous souhaitons étudier comment ce marqueur évolue en fonction de l'état attentionnel du sujet.

En utilisant les indications du sujet (pression du bouton) pour définir les conditions expérimentales de dérive attentionnelle et de concentration sur la respiration, nous montrons que les épisodes de dérive attentionnelle sont accompagnés par une amplitude accrue des basses fréquences EEG 1-3Hz delta et 4-7Hz theta. Cette observation est tout à fait compatible avec des études montrant la présence de fluctuations des activités cérébrales lorsque le sujet n'est pas activement impliqué dans le traitement d'une tâche nécessitant une attention soutenue vers l'environnement externe. Ceci est aussi en adéquation avec les études associant l'apparition du rythme théta avec des états de vigilance réduite tels que l'endormissement alors que les sujets essaient de rester vigilants. Par ailleurs, l'augmentation de la puissance théta lors de la dérive attentionnelle peut aussi être rapprochée de résultats montrant une corrélation positive entre l'activité théta et l'augmentation de la charge mnésique en mémoire de travail. En effet nous supposons que les pensées spontanément générées lors de la dérive attentionnelle se rapportent à la projection du sujet dans des situations futures ou passées, deux types d'opérations mentales sous-tendus par des processus mnésiques. Par ailleurs, l'activité des ondes théta est anormalement élevée chez des personnes souffrant de déficits attentionnels éprouvant des difficultés à rester concentrées ce qui est en accord avec notre résultat associant théta à l'état de dérive de l'attention. La diminution du rythme théta lorsque les sujets sont en état de concentration que nous observons entre en contradiction avec de nombreuses études associant la concentration sur un tache donnée à une augmentation du rythme théta. Cependant cette diminution a aussi été observée au cours d'une étude employant un protocole expérimental de méditation similaire au nôtre . Il est donc possible que la diminution du rythme theta varie en fonction de la direction de l'attention du sujet (internalisée ou vers une tâche exérieure) et des études supplémentaires seront nécessaires pour tester cette hypothèse.

L'étude des potentiels évoqués montre une différence de négativité relevée au niveau des électrodes frontales entre les PEs aux stimuli déviants et les PEs aux stimuli standards entre 90 et 120ms. Cette observation est compatible avec la négativité de discordance ou "mismatch negativity" (MMN) décrite dans la littérature comme une réponse cérébrale négative à la détection sensorielle d'un changement soudain dans le flux de perception auditive et ayant lieu dans une fenêtre temporelle d'approximativement 100- 150ms. Bien que cet effet soit controversé, l'amplitude de la MMN peut être modulée selon la direction de l'attention des sujets . Elle est notamment plus ample lorsque l'attention des sujets est engagée dans le traitement des stimuli . Nos résultats montrent que l'amplitude de la MMN entre stimuli déviants et standards est moins forte lors de la dérive attentionnelle que lors de la concentration, ce qui suggère, à l'image des résultats de Smallwood 2008 mentionnés en introduction, un désengagement des processus de traitement des stimuli associé à l'état de dérive attentionnelle. Il faut noter que, bien que la MMN soit généralement suivie du composant P3a, pic positif aux alentours de 300ms, indice de l'orientation automatique de l'attention envers un stimulus nouveau, nous n'observons ni P3a ni P300 analysable dans notre étude. Il est probable que dans notre étude, les stimuli déviants présentés de façon passive n'ont pas eu un effet de nouveauté suffisant pour induire une P3a. L'analyse des PEs indique également que l'amplitude de la composante positive à 200 ms (P2) est plus forte lors de la dérive attentionnelle qu'en état de concentration et est dans les deux conditions plus faible pour les stimuli déviants. Certaines études ont associées la diminution d'amplitude de P2 à l'augmentation du degré d'attention des sujets envers les stimuli. Ceci semble compatible avec l'idée selon laquelle lors de l'état de dérive attentionnelle l'engagement attentionnel des sujets vers les stimuli diminue. Toutefois, le composant P2 des potentiels évoqués auditifs n'a été que très peu étudié aussi est-il difficile de lui associer un rôle fonctionnel.

Ces résultats indiquent que la dérive attentionnelle est associée à un niveau réduit de vigilance, similaire aux premiers stades de la somnolence. Ceci est cohérent avec certains textes bouddhistes sur la méditation, qui représentent la dérive attentionelle comme un état de sommeil par rapport aux périodes où l'esprit est concentré. Notre étude est également à notre connaissance la première en neurosciences cognitives à utiliser des conditions expérimentales purement établies sur la base de l'expérience introspective des sujets.

Dans un second temps, je me suis intéressée plus spécifiquement à l'état de méditation. Il faut tout d'abord savoir qu'il existe de très nombreuses formes de méditation, dans des cultures différentes à travers le monde. La pratique de la méditation est souvent considéré par les neuroscientifiques comme étant un entrainement de l'attention. Selon les formes de méditation, l'attention est utilisé de facon plus ou moins focalisée, tout au moins lors des premières étapes d'apprentissage de la méditation. Tout d'abord j'ai réalisée une revue des travaux existants retraçant l'impact de l'entrainement à la méditation sur le système nerveux autonome, le cerveau, les fonctions cognitives et la régulation des émotions. Cette revue met en évidence des aspects positifs de la pratique de la méditation sur la santé physique et mentale lorsqu'elle est utilisée par des personnes souffrantes (stress chronique, dépression etc..) et suggère également un effet protecteur de la pratique de la méditation chez les personnes saines. Par exemple, des études suggère que la méditation protégerait de la perte neuronale et des modifications du sommeil liées au vieillissement normal.

Toutefois, concernant les modifications de l'activité EEG produites par la méditation, je n'ai pu dégager aucun consensus clair de la littérature. Outre l'intérêt pour la recherche fondamentale, la connaissance précise des activités EEG induites par la méditation pourrait s'avérer très utile pour la mise en place par exemple de thérapies basées sur la technique de contrôle de ses ondes cérébrales (neurofeedback).

Il est difficile de savoir si les différents résultats présents dans la littératures sont dus à des différences entre les protocoles expérimentaux utilisé ou à des différences entre les pratiques méditatives étudiées. Nous avons donc décidé de réaliser une étude comparative des activités EEG au cours de la méditation, en nous servant d'un seul et même protocole et équipement pour étudier 3 groupes de sujets issus de traditions de pratiques méditatives différentes ainsi que un groupe de sujet contrôles, ne pratiquant aucune forme de méditation. Les sujets méditants ont été recrutés sur la base de la durée de leur expérience avec la pratique de la méditation: nous n'avons recruté dans la plupart des cas que des personnes attestant d'une pratique quotidienne depuis un minimum de 5 ans dans une seule et même tradition. Les 3 traditions de méditation étudiées ont été choisie pour maximaliser les différences d'utilisation de l'attention entre chaque groupe. La tradition Himalayenne requiert la concentration sur la répétition de syllabes en sanskrit (mantra), la tradition Vipassana requiert la concentration sur la sensation de respiration puis sur les sensations du corps. Enfin la tradition Isha ne demande aucun contrôle particulier de l'attention. Les enregistrements nécessaires à cette étude ont eu lieu au centre de Recherche sur la Méditation de l'ashram SRSG à Rishikesh, en Inde.

Notre protocole impliquait 2 enregistrements successifs, ou blocs, de 40 minutes chacun, l'un réalisé dans et après l'élicitation d'un état de méditation et l'autre réalisé dans un état mental dit de contrôle consistant en une tâche de rappel de souvenirs autobiographiques. Dans chacun des blocs, les sujets réalisait une succession de tâches psychophysiques après une période de 20 minutes d'enregistrement sans stimulation aucune.

Les résultats que nous rapportons dans ce manuscrit portent sur cette période d'enregistrement de l'activité EEG induite par l'état de méditation et l état contrôle, sans aucune sorte de tâche psychophysique. Chaque groupe est composé de 16 sujets, et les groupes sont homogènes en âge. Nous montrons que tous les groupes de méditants avaient une amplitude de fréquence gamma 60-110Hz plus élevée par rapport aux contrôles pendant la méditation, indiquant peut-être des processus attentionnels différents chez les méditants. Aucune différence n'a été trouvée entre l'état mental contrôle et l'état méditatif chez les méditants, ce qui suggère que les modifications dues à la pratique longue de la méditation sont plus robustes que les effets de l'état mental de méditation par rapport à un état contrôle. Par ailleurs, le groupe de méditants Vipassana montre une amplitude des ondes de fréquence gamma 8-10Hz plus élevée que celle des autres groupes de méditants et du groupe contrôle, ce qui suppose là aussi des différences de processus attentionnels dans la pratique de la méditation Vipassana. Toutefois, une étude longitudinale sur des sujets avant et après le début de la pratique de Vipassana serait nécessaire pour déterminer si cette plus grande amplitude des fréquence 7-10Hz est acquise grâce à la pratique de la méditation où si les individus de la population générale ayant de fait une activité EEG de 7-10Hz plus élevée sont attirés par la pratique de Vipassana. Nos résultats présentés ici seront sans nul doute affinés dans le futur par l'analyse des tâches psychophysiques. Dans l'ensemble, notre étude souligne la nécessité de mieux définir ce que pourrait être le meilleur état de contrôle mental pour la méditation et l'intérê de réaliser des études associant différents types de méditation et un groupe contrôle.

Au cours de ce travail j'ai également exploré les méthodologies pour recueillir des informations subjectives pertinentes, notamment en utilisant l'entretien d'explicitation. Bien que préliminaire, les données recueillies par cette approche permettent d'entrevoir les possibilités de raffinement dans la description des états mentaux, par exemple en ce qui concerne les dérives attentionnelles. Nous prévoyons dans le futur que l'analyse des données physiologiques telles que le signal EEG pourront être affinées par l'utilisation de données subjectives acquises selon une méthodologie rigoureuse.

A la fin de ce manuscrit, je propose une synthèse de mes différents résultats, soulignant les différences entre les activités EEG de l'état de dérive attentionnelle, caractérisées par des oscillation de basses fréquences (1-3Hz et 4-7Hz) et celles de l' état de méditation, qui semble produire des oscillations de fréquence très rapide (60-110Hz). Les études EEG de la dérive attentionnelle devraient pouvoir être affinées grâce à l'utilisation de données subjectives produites par le sujet. Des pistes pour mieux comprendre son rôle fonctionnel sont évoquées, comme l'hypothèse d'une activité cérébrale en lien avec la consolidation mnésique qui se produirait en continu en état d'éveil et dont les dérives attentionnelles pourraient être l'expression phénoménologique. Concernant les études neuroscientifiques de la méditation, je souligne le besoin de mieux définir ce que devrait être l'état ou la population de sujets servant à contraster les activités cérébrales induites par la méditation. Nous n'avons pu dans les travaux présenté mettre en évidence une différence d'activité EEG chez les méditants entre l'état de méditation et notre état contrôle. Dans l état actuel de nos connaissance nous ne pouvons pas déterminer si cela provient d'une modification sur le long terme de l'activité cérébrale des méditants, qui modifierait leur activité EEG même en dehors d'une période de méditation proprement dite ou si cette observation est due à une trop grande ressemblance entre les processus de surveillance du focus attentionnel en oeuvre lors de la méditation qui se retrouveraient également lors de la tâche de remémoration des souvenirs. Enfin, l'état de dérive attentionnelle et celui de méditation sont intégrés dans le modèle des états de conscience de J.Allan Hobson, au côté des états de veille, de sommeil et de rêve. Cette première tentative de modélisation des états de dérives attentionnelle et de méditation au côté d'états de consciences plus classiquement étudiés appelle à la prise en compte de l'ensemble des caractéristiques de l'expérience consciente des êtres humains.

Dans l'ensemble, mon travail apporte de nouvelles perspectives pour l'étude la conscience humaine, mais la route reste longue avant que nous ne comprenions parfaitement les mécanismes sous-jacents de notre vie intérieure. Mon espoir est que les neurosciences cognitives aideront à une meilleure compréhension de l'esprit humain qui donnerait à chacun la possibilité de vivre et d'agir en adéquation avec sa nature.

Contents

Part I

General introduction

Chapter 1

On introspection, meditation and mind wandering: an introduction to the neuroscientific study of the mind

Contents

This chapter aims at providing a theoretical background regarding the study of mental states in cognitive neuroscience as well as basis concerning the study of attention and consciousness. I will also introduce what will be the major focus of this thesis: the study of meditation and mind wandering.

1.1 Subjective data and cognitive sciences, a brief history

1.1.1 The introspective approach at the beginning of the 20th century

Philosophers have long tried to describe our patterns of conscious experience. In the 17th century, Descartes established his view of dualism, stating that the seat of the soul was the pineal gland, influencing the body through a fluid delivered by the ventricles (Descartes and Rodis-Lewis, 1649/1988). Locke (1975) started classifying our experienced "ideas" into different categories depending on whether they emerged from sensation or from thoughts. Simmilarly, Hume et al. (1739/2007) distinguishes mental images from perceptual experiences in terms of their “strength” or “liveliness”.

One of the first scientific exploration of conscious experience came with introspective psychologists of the late nineteenth and early twentieth centuries.

> “ Introspective observation is what we have to rely on first and foremost and always. [...] Thoughts are the subjective data of which [the psychologist] treats, and their relations to their objects, to the brain, and to the rest of the world constitute the subject-matter of psychological science. Its methods are introspection, experimentation and comparison.”

, stated William James in his masterwork, *The Principles of Psychology* (James, 1890, chap.7,pg 197)

The early twentieth century was the time when the basis of psychophysics were being developed and introspection emerged as common methodology used in the first experimental psychology laboratories. Psychologist such as Wilhelm Wundt and Edward Titchener tried to understand how introspective experiences covaried with changes in external stimulation by presenting them carefully calibrated stimuli and training their subjects to take careful notes of their past or immediately occurring experiences (Danziger, 1980). Three main centers of experimental introspection were active: in France with Alfred Binet, in the United States with Titchener, a former student of Wundt, and in Germany with a group of psychologist lead by Külpe and Marbe known as the Würzburg school. During the decade between 1903 and 1913 experimental introspection flourished (Danziger, 1980). Nevertheless, at that time, researchers from the different groups could not agree on basic premises, leading to the persistent idea that results based on introspection were weak and not replicable. However, more contemporary reads of studies of that time reveal that, in fact, introspective psychologists of the beginning of last century were disagreeing not on the actual existence of subjects reports of such and such phenomenon but instead on their interpretations! (see Depraz et al., 2011, chapter 4, pg 203-204) A famous example is the disagreement between Titchener and the school of Würzburg on whether "imageless thoughts" exist or not: despite 20 years and thousands of hours spent in introspection in both laboratories to try solving the issue, neither side could settle the controversy (Hurlburt and Heavey, 2001). Closer to us, Monson and Hurlburt (1993) reviewed results from both the Würzburg and the Titchener' s schools and revealed that in both laboratories subjects gave highly similar description of "vague and elusive processes" carrying the entire meaning of a situation such as "a realization that the division can be carried out without a remainder" (Hurlburt and Heavey, 2001, Titchener quoted by). These "vague and elusive processes" were imageless thoughts for the Würzburg school but not for Titchener. The popular skepticism towards the use of introspective data that emerged at that time and can still be found today is mainly based on such theoretical division rather than on the question of replicability or reliability of the subject reports. In addition major criticisms against the use of introspection, some stemming from the prominent french philosopher Maine de Biran (1766-1824), argued that the subject could not both experience an event and report it at the same time. The observation of experience itself necessarily influence what is being observed. This came at a time where psychology transitioned to behavioural psychology.

1.1.2 Behaviourism

In 1913, John B. Watson (1878-1958) published a now classic text exposing his view of what psychology should be:

> "The time seems to have come when psychology must discard all references to consciousness; when it need no longer delude itself into thinking that it is making mental states the object of observation [...] If psychology would follow the plan I suggest, the educator, the physician, the jurist and the businessman could utilize our data in a practical way, as soon as we are able, experimentally to obtain them ", (Watson, 1913)

Another quote taken from yet another psychology textbook contemporary of Watson reinforce the underlying proposed view of psychology as providing possible application in the industrial and technical domain:

> "The practical end is to determine upon what human capacity depends and, in the light of this knowledge, to discover means of increasing man's efficiency", Pillsbury (1911), quoted in Danziger (1980)

It is easy to understand that in light of such materialistic goals, introspection lost momentum, and remained unpopular until the late 20th century. Yet, although behaviourism sets psychology as the science of behaviour and not the science of the mind, it is noteworthy that the "radical behaviourist", as he called himself, B.F Skinner (1904-1990) did not consider private events to be non existent or unimportant and even acknowledged that both private and public events have the same essential nature:

> " The statement that behaviourists deny the existence of feelings, sensations, ideas, and other features of mental life needs some clarification. Methodological [non-Skinnerian] behaviourism and some versions of logical positivism ruled private events out of bounds because there could be no public agreement about their validity. Introspection could not be accepted as a scientific practice, and the psychology of people like Wilhelm Wundt and Edward B. Titchener was attacked accordingly. Radical [Skinnerian] behaviourism, however, takes a different line. It does not deny the possibility of self-observation or self- knowledge or its possible usefulness. " (Skinner, quoted by Hurlburt and Heavey, 2001)

The rise of behaviourism and the fact that early leaders of the main introspection schools died without leaving successors pushed introspection into the background of psychological research.

In parallel with the development of experimental introspection, the philosopher Edmund Husserl, influenced by William James work, elaborated a new psychological theory: phenomenology. Phenomenology is the study of the structures of various types of experience, such as perception, body awareness, imagination, standing from the first-person - i.e, from the subjective point of view (Smith, 2012). At the basis of phenomenology Husserl placed what he called "intentionality", which states that experiences are directed towards objects in the world – in other words that a fundamental property of consciousness is that it is a consciousness of, or about, something. Thus our experience represents objects only through particular concepts, images or thoughts, etc. and these make up the meaning or content of a given experience. However these concepts, images or thoughts are distinct from the objects they represent (Smith, 2012). Phenomenology considers that conscious experiences have a unique feature, that is we do not observe or engage in conscious experiences but rather we live through them, we experience them. Thus the phenomenological approach to the study of a type of experience assumes that by living we acquire a certain familiarity with that experience. It is the structure of a type of experience that phenomenology wants to determine rather than the structure of a particular instance of that type of experience. During the 20th century, phenomenology took a central place in European philosophy, for example through the work of philosophers Martin Heidegger (1889-1976) and Jean-Paul Sartre (1905-1980), as well as Maurice Merleau-Ponty (1908-1961). We will see that, recently, there has been a regain of interest for phenomenology in Cognitive Sciences (1.2). But let's review first briefly the early beginnings of cognitive sciences.

1.1.3 Cybernetics and cognitive sciences

Between 1946 and 1953, the Macy Conferences, which were interdisciplinary gatherings of leading scientist, aimed at setting the foundations for "a general science of the working of the human mind" [1]. They developed contemporary cybernetics, the study of the structure of regulatory systems which subsequently gave birth to cognitive science (Dupuy, 1994). The brain was regarded as an information-processing unit, cognition as a representation of the perceived world, and both had to be modeled to be understood. Although wider in scope originally, cognitive science eventually adopted a reductionist view stating that understanding of neuronal mechanisms in the brain will bring understanding of higher order cognitive phenomena. In such it departs from behaviourism which did not consider the mechanisms of the brain as a valuable domain of investigation to understand human behaviours.

In the 1970s, Chilean biologists Humberto Maturana and Francisco Varela developed an alternative, non-representationist viewpoint contrasting with the classical positions in cognitive sciences and biology in general: they called it the autopoietic (or self-production) theory. According to autopoiesis, the necessary and sufficient condition to characterize a living being is the concept of functional relationship between its elements: any living being is a system continuously creating and transforming itself in a somewhat circular process (see figure 1.1.3) (Maturana and Varela, 1987).

An interesting implication of the autopoietic theory is that it is becoming impossible to distinguish what comes from the environment from what comes from the system itself, there is a structural coupling between the two. Applied to the notion of self, autopoiesis also implies that it is in perpetual transformation and grounded in impermanence, a way of thinking of the self that is not far from the Buddhist philosophy.

1.1.4 Consciousness studies and neurophenomenology

Until the end of the 20th century, the study of inner experience continued in psychology, although mostly based on the subject's verbalization - a practice that pushes forward language-based representation .

[1] http://www.asc-cybernetics.org/foundations/history/MacySummary.htm

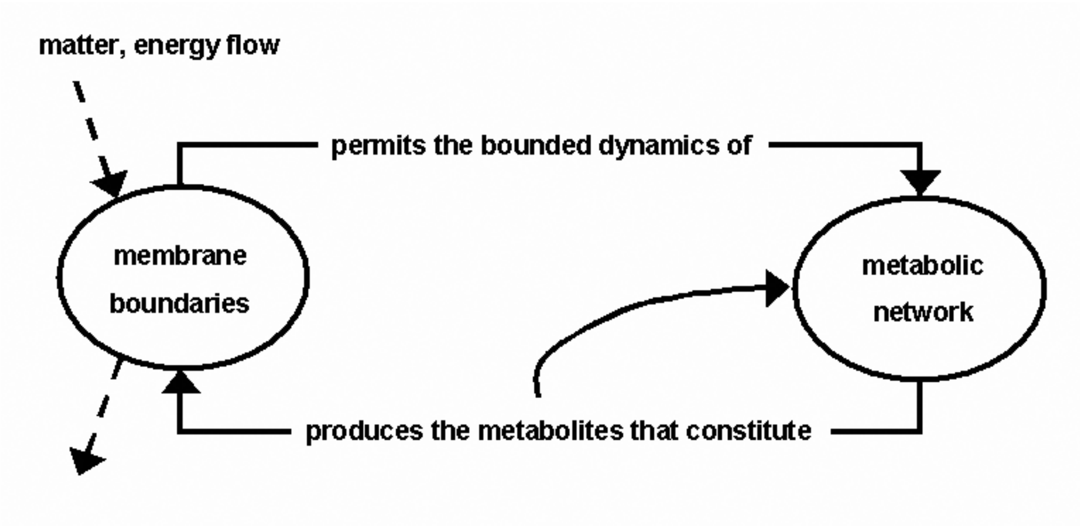

Figure 1.1: Example of an autopoietic system: the eucharyote cell. The autopoietic organization is defined as a unit by a network of production of components (chemical reactions) which (i) participate recursively in the same network of production of components (chemical reactions) that produced them, and (ii) carry out the network of production as a unit in the space in which the components exist (figure and legend from Rudrauf et al. (2003)).

Researchers were also looking at bypassing the problems posed by the used of subjective judgments. For example, Cooper and Shepard (1973) and Kosslyn and Pomerantz (1977) used chronometry to study the properties of mental images,

In the 1960s, scientific interest turned also towards studying positive, "extra-ordinary", mental states (Maslow et al., 1968). With the development of humanistic psychology, came a growing interest for Eastern traditions of meditation. Using electroencephalographic (EEG) recordings, a group of parisian researchers were amongst the first to publish reports of the brain activity during meditation (Henrotte et al., 1972; Banquet, 1973; Etévenon et al., 1973), along with a Japanese (Kasamatsu and Hirai, 1966) and American groups (Wallace, 1970).

EEG, a technique first introduced by the German physician Hans Berger in 1929, allows recording at the surface of the scalp the ionic current created by the synchronous activity of millions of cortical neurons. Oscillatory components may be seen on the electroencephalogram. They are elicited by cerebral networks including cortical, thalamic and brainstem structures. These oscillations are by convention characterized by their frequency and labeled with Greek letters. Thus the first rhythm observed by Berger, induced by eye closure in awake and calm subjects, was a large-amplitude signal oscillating at about 10Hz and that he called "alpha" rhythm – alpha being the first letter of the Greek alphabet, this is the one he chose. The faster rhythm present when

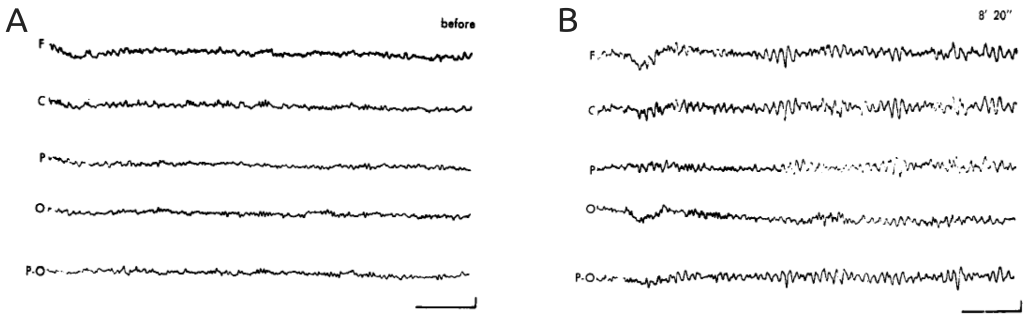

Figure 1.2: One of the first recording of meditation-induced changes in the EEG. A. EEG activity of a priest with open eyse before Zen meditation. B. EEG activity of the priest after 8 minutes and 20 secondes of Zen meditation, without regards of opened eyes: appearance of well-synchronized alpha waves. Figure adapted from Kasamatsu and Hirai (1966).

subjects had the eyes open was called "beta" rhythm. Ever since the initial report of EEG, researchers and clinicians have tried associating a specific rhythm with a specific cognitive state. For example figure 1.1.4 shows one of the earliest report of the appearance of alpha waves during meditation.

At about the same time, the american psychologist Charles Tart coined the term "altered state of consciousness" to define the "qualitative alteration of the general mental functioning leading one to feel his own consciousness as functioning radically differently than ordinarily" (Tart, 1972). American psychologists Jerome Singer and Kenneth Pope published *The Stream of Consciousness: scientific investigation into the flow of human experience* in 1978, a state of the art of studies on daydreaming, mental imagery, creativity and theories of consciousness (Pope and Singer, 1978).

However critics of the investigations of inner experience were still present. A particular influential one came from the research from Nisbett and Wilson (1977) who established that the subject often lacks awareness of the cause of their behaviours and set a conclusion about introspective reports in general:

> the accuracy of subjective reports is so poor as to suggest that any introspective access that may exist is not sufficient to produce generally correct or reliable reports (Nisbett and Wilson, 1977; Hurlburt and Heavey, 2001)

Nonetheless, as noted by Hurlburt and Heavey (2001) Nisbett and Wilson (1977) still recognized that accurate reports of inner experience are possible:

> " We also wish to acknowledge that the studies do not suffice to show that people could never be accurate about the processes involved. To do so would require ecologically meaningless but theoretically interesting procedures such as interrupting a process at the very moment it was occurring,

> alerting subjects to pay careful attention to their cognitive processes, coaching them in introspective procedures, and so on."

Starting in the 1980s, a slowly expanding community of neuroscientists and psychologists started to identify themselves as studying "consciousness". This gave rise to a stream of published experimental work and journals such as *Consciousness and Cognition* are created (Baars and Banks, 1992). Until that time, the word "consciousness" or even "awareness" had remained taboo.

In 1987, American businessman Adam Engel and renowned French/Chilean scientist Francisco Varela organized the very first meeting between the Dalaï-Lama and cognitive science researchers. This original meeting subsequently gave birth to the Mind and Live Institute, whose mission is:

> " to understand the human mind and the benefits of contemplative practices through an integrated mode of knowing that combines first person knowledge from the world's contemplative traditions with methods and findings from contemporary scientific inquiry. Ultimately, [the Institute' s] goal is to relieve human suffering and advance well-being." [2].

Francisco Varela became convinced that an interaction between cognitive science and the millenary traditions of self-observance and introspection developed in Buddhist meditative practices was a way not to miss an essential element in the exploration of human consciousness.

During the 1990s brain imaging technologies have seen great developments. On the electrophysiological side, higher montage density became available with 128 or even 256 channels compared to the standard 16/32 channels previously used. Magnetoencephalography (MEG) also developed towards more high density and less noisy recordings. Progress in signal processing also allowed for a better characterization of dynamical interactions in the brain. (Friston, 2002; Lachaux et al., 1999; Makeig et al., 2004). In 1992 the first studies to report the recording of blood oxygen level dependent (BOLD) signal variations in human using functional magnetic resonance imagery (fMRI) were published (Kwong et al., 1992; Ogawa et al., 1992; Bandettini et al., 1992). These technological improvements created a resurgence of interest for the study of consciousness from the neuroscientific point of view, allowing the investigation of the neural correlates of conscious experience.

However, even if these descriptive third-person approaches to consciousness flourished, the study of conscious experience from the first person did not follow immedi-

[2] `http://www.mindandlife.org/about/history/`

ately. In the mid-1990s, Francisco Varela developed the neurophenomenological approach for cognitive science to bring forth the first-person perspective, with an emphasis on neuroscience (Varela, 1996). The aim of neurophenomenology is to understand the nature of consciousness and subjectivity, as well as their relation to the body and brain. Thus reports of a given subjective experience are used to guide the analysis of neuroimaging data. Detailed description of the origins and principles of the neurophenomenology approach can be found in Varela (1996); Thompson (2005); Depraz et al. (2011).

Neurophenomenology derives from the embodied approach that Varela elaborated on the ground of autopeiesis and which states that to understand what the mind is, it is not enought to study the brain only but that one should the mutually interactive system the brain is forming with the body and the external environment (Varela et al., 1991).

Thus in neurophenomenology, experience is not seen as an epiphenomenon but considered central to an adequate understanding of the mind, and consequently needs to be carefully investigated. Varela considered that Cognitives Sciences account for the brain processes and phenomenological sciences accounts of the structure of human experience are mutually informative and enriching (Varela, 1996; Thompson, 2005; Varela et al., 1991):

> " [progress in the understanding of the human mind would require] to marry modern cognitive neuroscience and a disciplined approach to human experience, with respect to the continental tradition of phenomenology" (Varela, 1996, pg 330)

In 1999, Jonathan Shear and Francisco Varela edited a special issue of the *Journal of Consciousness Studies* titled *The view from within : first person approaches to the study of consciousness* (Shear and Varela, 1999). This special issue sat up a line of research to develop first-person methodologies. It is meaningful that an anniversary issue of the *Journal of Consciousness Studies* was entitled "*Ten years of viewing from within: the legacy of F.J Varela*". It was published in 2009, stating the progress that had been made towards the scientific establishment of first-person methods over the previous decade.

In the literature the neurophenomenological paradigm is now experimented and tested by a small but growing group of researchers. In cognitive science it has been used to guide the study of the dynamic of brain activity under condition of binocular rivalry, in which subjects were extensively trained to report their subjective experience during the task (Lutz et al., 2002), and successfully applied to the anticipation of epileptic seizure by combining data on the cerebral dynamic and data on the dynamic of the lived experience of a seizure (Petitmengin, 2007). In addition, neurophenomenology is also applied in the clinical domain, for example in the study of pain (Price et al., 2002). In neurophenomenological protocols, subjects are either very well used to the experience that is studied, for example in the case of epileptic crisis, or beforehand trained to identify and recognize the subjective experience to be studied, such as in Lutz et al. (2002)' s protocol. It is also in this context that contemplative mental training such as the one developed in Buddhist tradition of meditation can play a role in the scientific study of consciousness: because of their meditation training practitioners have become sensitized to even subtle variations in the moment-to-moment variations of their mental life, allowing for a deeper characterization of their ongoing experience (Lutz et al., 2007).

Developing methodologies to collect data on the lived experience of subjects for a scientific study of consciousness is anything but trivial. Indeed, as was shown by (Nisbett and Wilson, 1977), that we usually have only little awareness of our mental mechanisms and, when asked to describe them, we are usually quicker to express the general knowledge we have about them than to report the way we really lived them. This was the same type of critic that was made to introspection approach in the early 20th century. However, the ongoing effort to develop rigorous methods for collection of subjective data allied to the now high-resolution brain neuroimagery methods raise the hope to overcome the initial biases of introspective methodology and develop an experience-based science of consciousness.

There is a large number of methodologies to study conscious experience, in the next section I present techniques that are relevant in the context of my thesis project.

1.2 Methodologies to collect inner experience

1.2.1 Explicitation interview

The explicitation interview is a method initially developed by psychologist Pierre Vermersch and adapted to cognitive science by Claire Petitmengin, former student of Francisco Varela, as described in Petitmengin (2006). The explicitation interview allows collecting *a posteriori* lived experience. The interviewer guided the subject (ie. the interviewee) to evoke a particular situation and precisely describe it and guiding him to focus on the structure of the experience rather than on the description of its semantic meaning. The explicitation interview can be compared to a non-inductive guidance of introspection (Vermersch, 2009).

This interview technique is inspired by various works on subjective experience such as Husserl' s phenomenological approach of the study of consciousness, Milton Erickson' s practice of psychotherapy as well as meditation techniques. In addition it is also based on the work of psychologist Pierre Vermersch who studied the inner gestures leading to accurate introspective reports (Vermersch, 2009).

The explicitation interview has been incorporated in the neurophenomenological program and is since being used by a growing number of cognitive scientists (Petitmengin, 2007; Maurel, 2009; Petitmengin and Bitbol, 2009).

1.2.2 Experience sampling

Experience sampling, also found under the term thought sampling, methodology implies to randomly interrupt the subject from his ongoing activity with a probe requiering him to immediately pay attention to his ongoing inner experience at the moment of the interruption. Depending on the goal of the study, the nature of the question might vary. For example, during execution of a given task, the subject can be interrupted and ask wether his attention was or not on the task (see for example Christoff et al., 2009; Smallwood et al., 2008). Experience sampling can also be used in a more general fashion, as for example in Russel Hurlburt' s Descriptive Experience Sampling (DES) procedure. DES uses a beeper to randomly cue subjects, who are evolving in their daily life, to report their ongoing experience at the moment they heard the beep. Subjects have then to put in a notebook the characteristics of that moment and, within 24 hours, will complete an in-depth interview to describe that particular moment (Hurlburt and Heavey, 2001; Hurlburt and Schwitzgebel, 2007) Experience sampling can be found in laboratory set up, coupled or not with cerebral imaging or in natural environment - the subjects in that case are carrying a device delivering them the probes during the day.

1.3 Mind wandering and meditation, two aspects of conscious experience

1.3.1 Attention, consciousness and awareness

Resembling Poe' s *Purloined letter*, the stream of consciousness is always present for us, even if we don't always notice it.

For example, it is most likely that during the course of reading this manuscript your attention will wander. Your eyes may keep going through the lines and you will continue reading mindlessly with your mind busy with other thoughts. It may take you some time to realize that your attention is not focused on your reading material anymore. This phenomenon is termed “zoning out” and is almost ubiquitous (Schooler et al., 2004). Zoning out while reading sheds light on the complexity of the processes of consciousness.

What is happening in our attentional and conscious processes during a zoning out episode ?

Let us first start by defining some important terms such as “attention”, “consciousness” and “awareness”. For this, I will rely on the definition given by Endel Tulving in his paper *Memory and Consciousness* (Tulving, 1985):

> “ ‘Consciousness’ refers to a particular capability of living systems, whereas ‘awareness’ refers to the internally experienced outcome of exercising this ability in a particular situation [...] ‘Attention’ [...] refers to the control that the organism, or environmental events, can exert over the direction of consciousness in the selection of the ‘contents’ of awareness.”

Thus coming back to the phenomenon of zoning out, at some point attention gets redirected, and awareness switched from the reading material to a random thought. In addition, there is a specific amount of time when the subject is not aware that he is not reading. Eventually, he realizes he has zoned out and is actually not reading anymore.

This phenomenal dissociation between the content of awareness and the explicit recognition of it led psychologists and philosophers to propose the existence of a meta-level of consciousness (Jack and Shallice, 2001; Schooler, 2002). Meta-consciousness refers to the consciousness of one’ s awareness contents in the same way as meta-cognition refers to the knowledge about one’s own knowledge (Nelson, 1996). Meta-consciousness is thus distinct from phenomenal consciousness, that is the content of awareness. The psychologist Jonathan Schooler (2002) has outlined a temporal dissociation between phenomenal consciousness, that is conscious experience , and the meta-conscious processes allowing the explicit appraisal of the experience (see Figure 1.3.1).

1.3.2 Mind wandering and meditation

Zoning out while reading is an instance of a more general phenomenon called mind wandering. Mind wandering is the emergence of thoughts that unvoluntarily attract the attention away from the current task (Mason et al., 2007; Smallwood and Schooler, 2006). According to a recent large scale experience sampling study, such at-

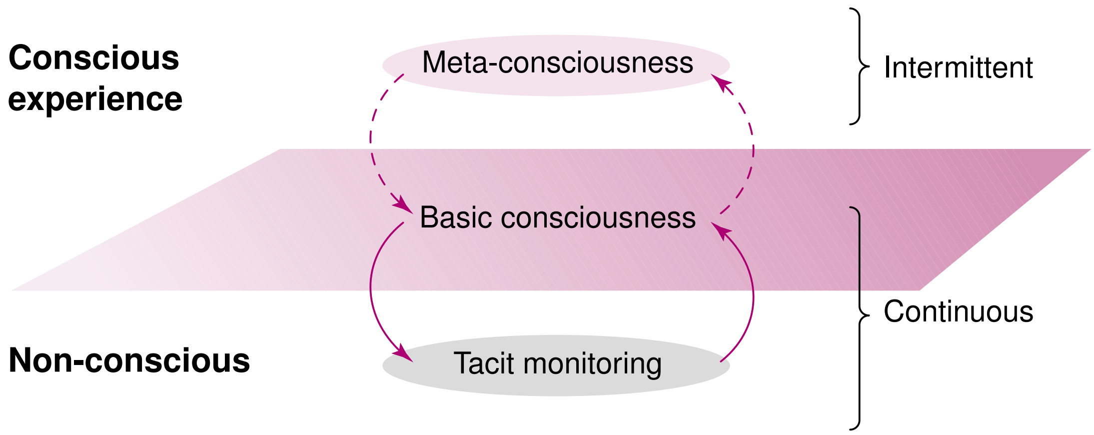

Figure 1.3: Schematic of the relationships between the different levels of meta-conscious, conscious and non-conscious processes. Basic consciousness, equivalent to phenomenal consciousness, is a continuuous experience throughout the waking state. At the non-conscious level, basic consciousness is monitored to check its adequacy with current goals. Meta-consciousness processes are implemented intermittently depending on psychological or physiological changes, for example a strong emotional response or the detection of goal failure (figure from Schooler (2002).

tentional drifts represent almost 50% of people mental experiences in their daily lives (Killingsworth and Gilbert, 2010).

The fleeting quality of attention has long been recognized in the Theravada Buddhist literature, which calls it the "monkey mind" (Gunaratana, 2002). It is said that the following metaphor was given by the Buddha:

> " Just as a monkey swinging through the trees grabs one branch and lets it go only to seize another, so too, that which is called thought, mind or consciousness arises and disappears continually both day and night." (Chodron, 1995)

In the practice of all meditation traditions, one of the first step is to realizes that the mind wander all the time. Any time a practitioner notices that his attention has turned towards self-centered thoughts he has to redirect it towards the object of meditation. It is interesting to note that the word meditation - which latin roots means *to reflect upon*- is used as a translation of the pali word *bhavana*, meaning *mental cultivation* (Gunaratana, 2002). Figure 1.4 is an illustration of the meditation training in Tibetan Buddhism.

Thus meditation traditions consider that natural spontaneous occurrence of thoughts or ideas are not necessarily the most beneficial to human being and provide teaching and training to stabilize attention. Are there biological and cognitive basis arguing for a detrimental effect of mind wandering ? Equally, using the tools of neuroscience,

Figure 1.4: The different stages of a monk calming his mind through meditation training, from bottom to top of the picture. The mind is figured as an elephant, distraction as a monkey, and effort as fire. The bottom of the painting represents the onset of meditation training. The mind wanders so much, it is represented by a muddy elephant led by a monkey while the monk is running after it. Half-way up the painting, it is now the monk leading the elephant which is also partly clean. Notice the monkey is still interfering by pulling the elephant tail. Further up, the monk only is in charge of the clean elephant, and say goodbye to the monkey. Soon after, the monk can get to ride the elephant. Arriving at the top, the monk is fully in charge of his mind, the elephant, and now rides down to put its power in good use. Picture from the Shelley & Donald Rubin Foundation, `http://www.himalayanart.org/image.cfm/59661.html`

can we find evidences for the positive effects of meditation ? These two questions will guide us through the present work.

1.4 Summary and aim of this thesis

The scientific investigation of consciousness developed at the end of the 19th century but had to face strong criticisms leading to the loss of interest of the mainstream psychologists and scientists. After the 1950s and the birth of cognitive sciences, a few researchers started to apply neuroimagery techniques to the study of altered states of consciousness, such as the ones reached during meditation. Meanwhile, psychologists were also reviving the study of subjective experience. From the 1990s, a research community started to built up around the study of consciousness. Progress in neuroimagery and data analysis made possible to record more and more precisely brain activity in difference states of consciousness. In parallel to these technical progresses, scientist Francisco Varela warned against the dangers of considering only observable data to understand the human mind and consciousness. He advocated taking into account the subjective experience as well, and developed methodologies avoiding the flaws of the early introspective approaches some of them on millennium Buddhist practices of introspection through meditation. This also, for the first time in modern science, created a bridge between cognitive science and spiritual traditions. In this view, attention has to get to stabilize through the practice of meditation if one wants to study his own mind. Indeed it is the most common experience of each and everyone that, when left with no distinct focus, our attention is fluctuating, jumping from thought to thought or from one memory to another. Even when subjects are given explicit instructions on a given task to accomplish, they often found that their attention has drifted toward unrelated thoughts. If meditation traditions has developed over the centuries and still remains active today, can we find any scientifically valuable reason for their affirmation ? What is the effect of mind wandering on the brain activity ? Conversely, what is the effects of long term training in meditation on the brain ? These are the questions I will address in this thesis.

In the first part of the manuscript, chapter 1 presents the evolution of the study of consciousness in psychology and cognitive science during the past century and introduces the ancient mental training of meditation traditions as a way to investigate consciousness and focus attention. It also depicts method to study attentional lapses which are central to meditation practices.

In the second part, we will focus on the neuroscientific study of mind wandering phenomenon. After a review of the existing work and theories, chapter 3 will present a first experimental study aiming at characterizing the brain EEG dynamic during episodes of mind wandering. Chapter 4 is a preliminary and exploratory study of the phenomenology of mind wandering, using the explicitation interview and online questionnaires.

The third part is dedicated to the study of meditation, starting with an introduction to the paradigm currently in use for the scientific investigation of meditating states in chapter 5. Then, chapter 6 reviews the literature regarding the effects of meditation on the body and the brain. Finally, chapter 7 is an experimental report of a comparative study of the EEG correlates of meditation, involving 64 subjects from 3 different meditation tradition and a non-meditator control group.

A last chapter 8 presents a general discussion and synthesis of this work and its consequences for consciousness research.

Although chapter 3 and chapter medit-review are based on published work, we decided not to present them under their publication format to ensure the fluidity of reading with the rest of the manuscript.

Part II

Mind wandering

Chapter 2

Introduction

Contents

This part of the manuscript presents our mind wandering study. In this introductory chapter, we are presenting a brief review of the existing litterature.

2.1 Theoretical aspects on mind wandering

Since you've started reading this manuscript, there is little doubt that you have experienced mind wandering several times. For example, you might have found yourself thinking about something else, such as your plans for the next week-end. It is even likely that, at times, you have found that your eyes had reached the end of a page and you had no idea of what the page was about.

At the end of the 19th century William James already devoted an entire chapter to the discussion of the fleeting quality of what he called the stream of thoughts (James, 1890). Although an important part of our mental life, thoughts that are not directly goal driven have not elicited a lot of interest from mainstream science until recently. References to the formal study of undirected thoughts can be found starting from the 1960s, with the work on daydreaming of pychologists Antrobus and Singer (Antrobus et al., 1964, for example).

Figure 2.1 shows the fast growth of the number of publication related to mind wandering since the start of the 2000s.

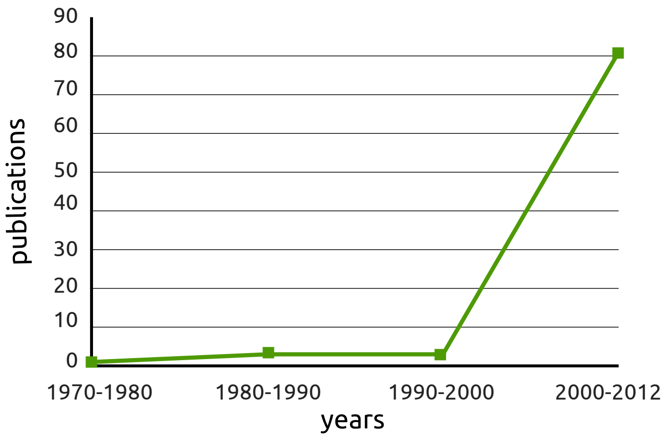

Figure 2.1: Evolution of the numbers of publication having the term "mind wandering" either in its title or abstract and referenced in PubMed from 1970 to July 2012

2.1.1 Terminology of mind wandering research

Like any developping field, the study of mind wandering lacks of an established terminology. For example, references to mind wandering can be found across the literature, under various terms such as "task-unrelated images and thoughts" (Giambra, 1989), "stimulus independent thought" (Teasdale et al., 1995), "task-unrelated thought" (Smallwood et al., 2003), "incidental self-processing" (Gilbert et al., 2005), "inner speech" (Morin, 2009), "momentary attentional lapses" (Weissman et al., 2006) or also "spontaneous thoughts" (Christoff et al., 2008) and of course "mind wandering" (Mason et al., 2007).

Recently, Christoff (2012) have proposed criteria to distinguish between 3 categories of undirected thoughts: "stimulus independant thoughts", "spontaneous thoughts" and "mind wandering". Christoff (2012) retains the criteria of intentionality and relation to the task and current sensory information to help define between the three categories. However, distinction between the different categories remains fuzzy as a mind wandering episode may exhibit multiple traits. For example Christoff (2012) proposes that mind wandering occurs only in the context of performing a task and can be either deliberate or unintended. Unintended mind wandering in this context resembles "spontaneous thoughts". In addition, a mind wandering thought may be triggered by an environmental stimulus or be stimulus independent - and in that case the definition overlap with "stimulus independent thoughts".

Thus much work is still needed before establishing a clear taxonomy that would allow mind wandering researchers to accurately qualify the type of thoughts subjects experience. In chapter 4 we present our own attempts to better define thoughts occurring during mind wandering episodes.

2.1.2 Type of tasks to elicit mind wandering

Behavioral examination of the context of occurrence of mind wandering indicates that when a primary task is simple or automatized enough not to monopolize all attentional resources, the mind is likely to wander (Robertson et al., 1997; Smallwood et al., 2003, 2004). In addition mind wandering impairs task performances only in cases where the task still requires a certain amount of controlled processing (Teasdale et al., 1995). Thus, favoured tasks to study mind wandering include tasks that can easily be automated such as signal detection tasks (Smallwood et al., 2004), inhibition of response tasks (Smallwood et al., 2008), or easy working memory tasks (Mason et al., 2007).

2.2 Experience sampling of mind wandering and brain activity

The experience sampling methodology 1.2 is one of the most popular to collect the occurrence of mind wandering events. By explicitly asking subjects to report the content of their thoughts, experience sampling methods allow collecting mind wandering events irrespective of the degree of awareness the subject has of these events.

In the 1960s, Singer and Antrobus (Pope and Singer, 1978) had their subjects report on a notebook the content of their thoughts each time a beep signal occurred. This approach is still in use today and have been adapted to contemporary technologies, such as in Killingsworth and Gilbert (2010)'s study using a smartphone application.

Experience sampling to study mind wandering is also commonly done during the execution of a laboratory task designed to favor the occurrences of mind wandering episodes – one popular task being the rare target detection paradigm. For example, subjects are asked to press a button in response to all numbers presented to them, except for number 3 - which comes up only rarely. Subjects are regularly interrupted during the performance of the task by a probe requesting them to report the content of their experience just prior to the presentation of the probe: where they focused on the task or thinking of something else (ie. where they "on" or "off" task?). Their performances are then examined both in terms of their response to the probe and of their target detection efficiency. Using this type paradigm, Giambra (1995) show that subjects had decreased performances in the rare-target detection task when they were mind wandering.

Mind wandering research also couple experience sampling with neuroimaging protocols to study the effect of mind wandering on brain activity. This line of research have been triggered by the discovery of a network of areas activated during the "default mode" activity of the brain when the subject is resting (Greicius et al., 2003; Raichle et al., 2001). The main hypothesis is that mind wandering could be the phenomenological experience of this default mode activity. Studies in fMRI have found increased activity of areas of the default mode network as well as higher recruitment of frontal executive networks during periods with high degree of mind wandering Mason et al. (2007); Christoff et al. (2009); Stawarczyk et al. (2011b).

Regarding EEG studies, Smallwood et al. (2008) show using mean event-related potential (ERP) analysis that the amplitude of the P300 ERP component - a physiological marker of attentional redirection - was reduced during mind wandering. Based on this results they suggested a decrease in attentional resources directed towards stimulus processing during periods of mind wandering.

Studies of the resting state both in simultaneous EEG and fMRI recordings have found that the activity in different EEG frequency bands is spontaneously fluctuating at rest and can be correlated to spontaneous fluctuations of the fMRI BOLD signal (Laufs et al., 2006; Mantini et al., 2007). These fluctuations seem to underlie two distinct modes of cerebral activity: a mode dominated by fast frequency waves (12-30Hz, beta) that may index higher degrees of task-related attention (Ray and Cole, 1985; Laufs et al., 2006), and a mode dominated by slow 3-7Hz theta waves oscillations that has been linked to decreased sustained task-related attention and diverse stages of transition from wake to sleep (Loomis et al., 1937; Makeig and Inlow, 1993; Klimesch, 1999; Smit et al., 2005).

Thus, there are evidences suggesting the existence of spontaneous fluctuation between attention directed toward the external and attention directed toward the internal environment. ERP results from Smallwood et al. (2008) suggest that mind wandering is associated to the inwards direction of the attention. However ERP analysis does not inform us on the underlying brain dynamics associated with mind wandering. This is the question we try to tackle in the next chapter.

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Chapter 3

EEG correlates of mind wandering

Contents

This chapter is based on a research article published in 2011, Braboszcz and Delorme (2011). To study the brain dynamic of mind wandering, we designed an EEG experiment in which the subject is doing a breath counting task and has to press a button whenever he realizes a thought is occurring . In contrast with classic thought sampling methods our task relies only on the pure introspective habilities of the subject to signal occurrences of mind wandering. If this approach results in missing out mind wandering episodes that do not come in the subject's awareness, it is a first attempt to test wether it is possible to rely only on the introspective skills of untrained subjects to accurately collect mind wandering episodes.

3.1 Introduction

Based on the litterature (see chapter 2, we hypothesized that mind wandering would be associated with decreased vigilance and increased delta and theta power. In addition, to further characterize the brain activity during mind wandering we wanted to add sensory stimulation, allowing us to later perform evoked related potential analysis. Indeed, it has been shown that brain evoked response to external stimuli change with the degree of vigilance or sleep stage. For example, the negative brain response to the sensory detection of a sudden change in the flux of auditory perception, called mismatch negativity (Näätänen et al., 2007), is reduced during the early sleep stages and drowsiness (Lang et al., 1995; Winter et al., 1995). Following our hypothesis that the mind wandering state should be associated with decreased vigilance, we added an auditory oddball protocol to our experiment, in order to elicit a mismatch negativity in the ERP response. We expected to observe a decrease in the mismatch negativity amplitude during the mind-wandering state compared to the breath focus state.

In sum, we designed an experiment allowing subjects to experience mind wandering in conditions we believe to be as close as possible to the way they are experiencing it in their daily life. We chose a simple concentration task - a silent breath counting task - that only requires weak cognitive involvement from the subject, a characteristic known to favor the induction of mind wandering (Giambra, 1995; Cheyne et al., 2006). Simultaneously we presented frequent and rare pure-frequency auditory stimuli that subjects were instructed to ignore. We used the subjects indications of mind wandering events and the auditory stimuli to assess both the brain EEG spontaneous and evoked activity during the mind wandering and breath concentration states.

3.2 Methods

3.2.1 Participants

Sixteen volunteers from the laboratory staff and local universities (8 females and 8 males; age 19-36 years old, mean: 27 and standard deviation 5) gave written consent to participate to the experiment. Participants stated that they were not taking any substances or medications that could potentially affect their concentration nor having histories of major psychological disorders or any auditory deficiencies. Before starting the experiment, all participants read the instructions and had the possibility to ask questions about the experiment before giving written consent to participate in the experiment. As detailed below, 4 of the 16 participants had to be excluded because they did not report enough mind wandering episodes.

3.2.2 Procedure

Participants sat in a dark room. We asked them to keep their eyes closed during the recording session. Participants were instructed to count each of their breath cycles (inhale/exhale) from 1 to 10. As subjects often lack immediate awareness of their mind wandering episodes (MWE), we could not ask them to signal MWE occurrence at the moment their attention was drifting away from the task. Instead, we asked them to indicate whenever they realized their attention had drifted, that is whenever they gained meta-consciousness (Schooler, 2002) of their mind wandering episodes. We asked subjects to hold a button in their right hand and press it whenever they became aware of having lost track of their breath count (see figure 3.1). The following instructions were given to subjects to define what was meant by losing track of the count: “you stopped counting”, “you counted over 10 breaths” or “you had to reflect intensively to figure out what was the next count”. Once they pressed the button, participants were instructed to bring their focus back to their breath and start counting again from one. We read task directions to participants and made sure they understood them. The experiment lasted about one hour and 10 minutes, split into three blocks of 20 minutes separated by five minutes of rest. At the end of each block, we asked subjects to evaluate their alertness level during the past session (“Did you feel like falling asleep?”), their eye movement activity “Did you open your eyes – if yes can you estimate how many times”, and their subjective experience when reporting mind-wandering episodes (“Did you press the button? If yes, what was your subjective experience?”). None of the participants reported systematically opening their eyes and none of the participants reported falling asleep. However, 6 of the 12 se-

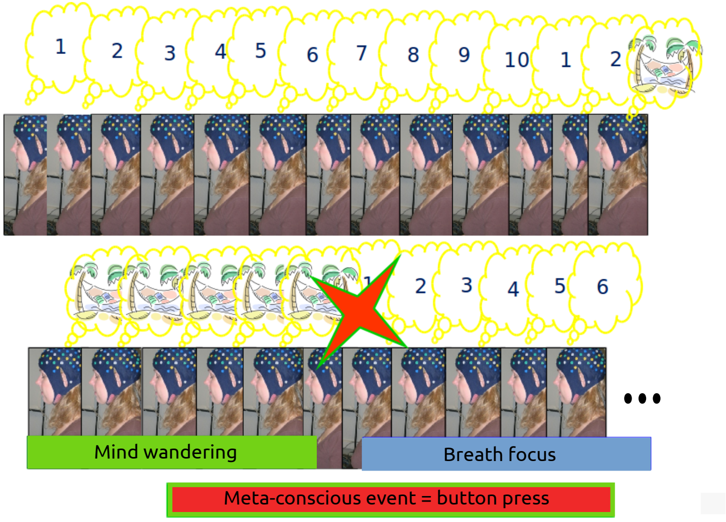


Figure 3.1: Experimental protocol. Subjects continuously count their breath from 1 to 10 while sitting eyes closed in a dark room. Any time they find themselves not counting anymore, thinking of something else or having lost the count they have to press on a button held in their hand. In parallel they are passively listing to a stream of auditory stimuli organized in an oddball sequence. Their EEG activity is being recorded using a 128 electrodes system.

lected participants reported some level of drowsiness at one time or another during the one-hour experiment (see Discussion).

3.2.3 Auditory stimuli

While performing the breath counting task, subjects were also presented with a passive auditory oddball protocol that they were instructed to ignore. The auditory oddball protocol was composed of pure sounds of 500 Hz for the standard stimuli (80% of the stimuli) and 1000Hz for the oddball (20% of the stimuli). Each sound lasted 100 ms with 10 ms linear amplitude rising and falling times. Inter-stimulus intervals randomly varied between 750 and 1250 ms. Oddball stimuli presentation was pseudo-random to ensure there were never two oddball stimuli presented successively. Auditory stimuli were calibrated at 72dB and played through a loudspeaker located at 1.20 meters in front and 45 degrees on the right of the subject.

3.2.4 Recording

We recorded data using a 128-channel Waveguard™ cap (Advanced Neuro Technology Company – ANT) out of which we used 124-channels - electrodes AFZ, PO6, TP7, and PO5 were damaged and left out. We plugged the Waveguard™ cap into two synchronized 64-channel EEG amplifiers also from the ANT Company. We kept most electrode impedances below 5KOhm although about 10% of the electrodes still had higher impedance at the end of preparation - all impedances were kept below 20Kohm as recommended in ANT ASA 4.0 software user's guide – ANT recommendation is higher than the standard 5 Kohm because of the high impedance of its amplifier. We used M1 mastoid electrode as reference and sampled the data at 1024Hz. We also recorded EKG by placing two bipolar electrodes on each side of the subject's torso.

3.2.5 Artifacts correction

We first removed bad electrodes – from 2 to 17 bad electrodes per subject. We then manually pruned the continuous data from non-stereotyped, unique artifacts such as paroxysmal muscles activity - high frequency activities with large amplitude over all electrodes - as well as electrical artifacts resulting from poor electrode contacts - short-lasting aberrant oscillatory activity localized at a few electrode sites. We then used Infomax Independent Component Analysis (Infomax ICA) on the pruned data to reject artifacts. For each subject, we visually identified and rejected one to five well-characterized ICA components for eye blink, lateral eye movements, and temporal muscle noise (Delorme, Sejnowski et al. 2007). We used visual inspection of component scalp maps, power spectrum and raw activity to select and reject these artifactual ICA components.

3.2.6 Data processing

Data processing was performed under Matlab 7.0 (The Mathwork, Inc.) using the EEGLAB 7.x toolbox (Delorme and Makeig 2004). We first downsampled the EEG data from 1024 Hz to 256Hz and performed high-pass filtering at 1Hz using a non-linear elliptic filter. In addition, we applied an elliptic non-linear notch filter between 45 and 55 Hertz. For each subject, we then segmented the EEG data into 20-second data epochs centered on subjects' button presses. We considered that participants were mind wandering during the 10-second period that preceded the button press and we considered that participants were concentrating on their breath during the 10-second period that followed the button press (Christoff et al., 2009). Four subjects did not have enough clean data epochs to be considered for further analysis - the four subjects had six, five, five and one clean epochs respectively. All the selected subjects had between 13 and 52 of such 20-second clean EEG data epochs (mean of 30 per subject; standard deviation of 14), ensuring that, for each subject, there would be at least 20-30 stimuli in each condition to compute ERPs (Kappenman and Luck, 2010) – see ERP analysis below.

The total number of analyzed mind wandering event across all subjects was 358.For each of the two conditions, mind wandering and breath focus, we also extracted data epochs from one second before to two seconds after the presentation of auditory stimuli. So that auditory stimuli do not occur too close to a button press, we removed all three-seconds data epochs containing a button press - thus button presses were at least one second prior to the stimulus or at least two seconds after the stimulus. This procedure ensured that the brain activity related to the button press does not contaminate our analysis. In addition, we processed brain activity from electrodes (Oz, Fz) that were not over pre-motor and motor regions limiting potential contamination of button press brain related activity. We thus obtained four groups of data epochs – oddball and standard stimuli defined over two conditions: mind wandering and breath focus. We computed mean event related potential (ERP) using a -300 to 0 ms baseline and we performed ERP visualization after applying a 30Hz linear low pass filter - note that we used the non-filtered data for computing statistics. We counted a total of 4326 standard stimuli (mean of 180 per subject; standard deviation of 101) and 1040 oddball stimuli (mean of 43 per subject; standard deviation of 23).

3.2.7 EEG time-frequency analysis

We applied Morlet wavelet decomposition (Goupillaud et al., 1984) to both the 20-second long data epochs time-locked to button presses and the short 3-second data epoch time-locked to auditory stimuli. We used 200 linearly-spaced time points and a series of 100 log-spaced frequencies ranging from 1 Hz to 100 Hz, with 1.5 cycle at the lowest frequency increasing linearly and capping at eight cycles at 30 Hz. For long 20-second epochs, we visualized absolute log power - 10*log10(X), X being absolute power at a given time-frequency point. For short three-second epochs time-locked to auditory stimuli presentation, we also removed baseline spectral activity by subtracting the pre-stimulus average baseline log-power at each frequency (Delorme and Makeig 2004) .

3.2.8 Statistics

Statistical tests were performed on ERPs, time-frequency maps and topographic maps using two-tailed paired parametric student t-test (df=11). Since most representation involves hundreds of tests, correction for multiple comparisons was performed using the Montecarlo and the cluster method as developed by Maris (2007). This method first measures the extent of 1-D (length) or 2-D (surface) of significance regions (uncorrected) and then tests if the extent of these regions is significant using a Monte-Carlo approach. For channel topographies, we set the number of channel neighbors to 4.5 before running Maris and Oostenveld (2007) Matlab function. We also tried FDR (False Discovery Rate) (Benjamini and Yekutieli, 2001) to correct for multiple comparisons and obtained similar results compared to the cluster method.

3.3 RESULTS

3.3.1 EEG activity time-locked to meta-consciousness events

The time frequency analysis of EEG data time-locked to meta-consciousness event – button press - shows a significant influence of the subject's attentional state at all frequency bands from 2 to 25 Hz (figure 3.2. The most pronounced state-associated change on the EEG spectral activity occurs in the theta (4-7Hz) band where absolute spectral power is significantly higher in the mind wandering state compared to the breath focus state. This effect is observed at all electrode sites and is larger over occipital and parieto-central regions. Absolute power in the delta band (2-3.5Hz) showed the same trend although the largest power difference was now observed over the fronto-central region. By contrast occipital alpha (9-11 Hz) and fronto-lateral beta (15-30 Hz) power was significantly lower in the mind wandering state compared to the breath focus state. For each subjects, figure 3.3 shows the evolution of the difference between alpha and theta activity at electrode site Oz between mind wandering and breath focus.

Half of our subjects reported some level of drowsyness during the course of the recording. To make sure that our data were not highly affected by these subjects, we computed the same time-frequency decomposition as figure 3.2 but including only subjects that did not report any drowsiness. As it can be seen in figure 3.4, the time-frequency patterns are almost identical to the ones visible in figure 3.2.

During the transition associated with the meta-consciousness (MC) event, the alpha frequency band in figure 3.2 is not only affected in terms of amplitude but also in terms of peak frequency. The peak frequency appears to increase by about 1 Hz after the meta-conscious event for a period of about 2 seconds. To test if this observation was significant across subjects, we defined three time windows, W1 from -6 to -4 second before the MC event; W2 from 0 to 2 seconds after the MC event; W3 from 6 to 8 seconds after the MC event. For each subject and for each time window, we then manually assessed the alpha peak frequency by taking the frequency of maximum power between 8 and 12 Hz on the power spectrum – the power spectrum was computed by averaging log-power values of figure3.2 over the windows of interest W1, W2 and W3.

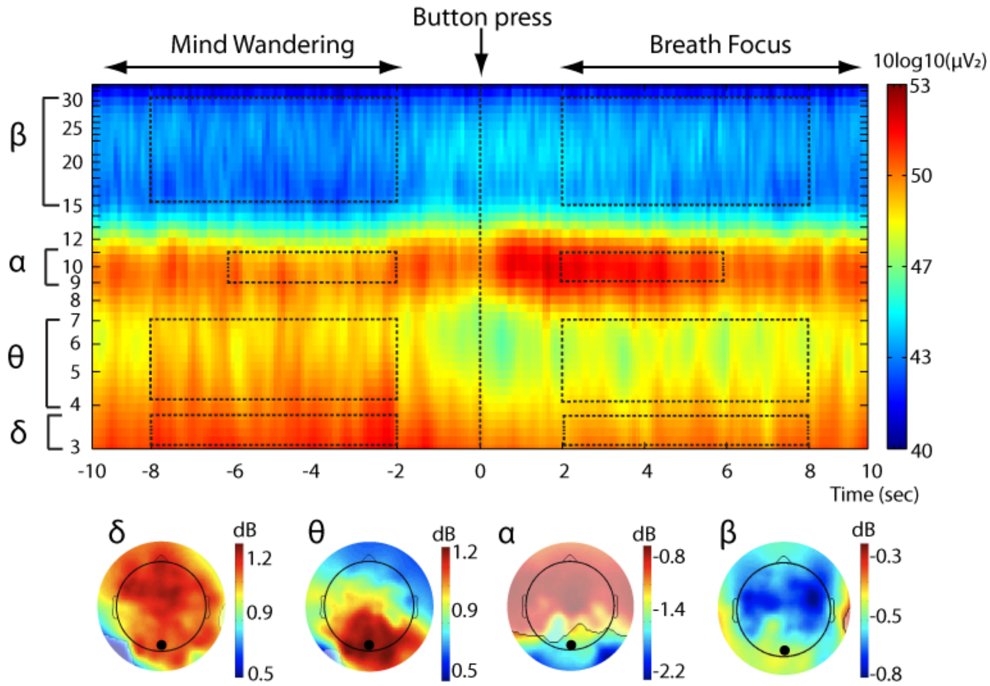


Figure 3.2: Time frequency decomposition of transition from mind wandering to breath focus at electrode site Oz. Mind wandering was defined as the period preceding the meta-conscious event (button press) and breath focus was defined as the period following the meta-conscious event. Topographic maps of power difference are shown for the 2-3.5 Hz (d), 4-7 Hz (q) , 15-30Hz (b) frequency bands from -8 to -2 seconds before and from 2 to 8 seconds after the button press. Topographic map of differential power is shown for the 9-11Hz (a) frequency band from -6 to -2 seconds before and 2 to 6 seconds after the button press. (unlike other frequencies bands, the difference of power in the alpha band between mind wandering and breath focus was not significant for a larger time interval). Areas of statistical significance ($p<0.05$) are highlighted on the topographic maps (shaded areas represent non-significant regions for a; all electrodes are significant for other frequency bands). The black dot represents the position of electrode Oz.

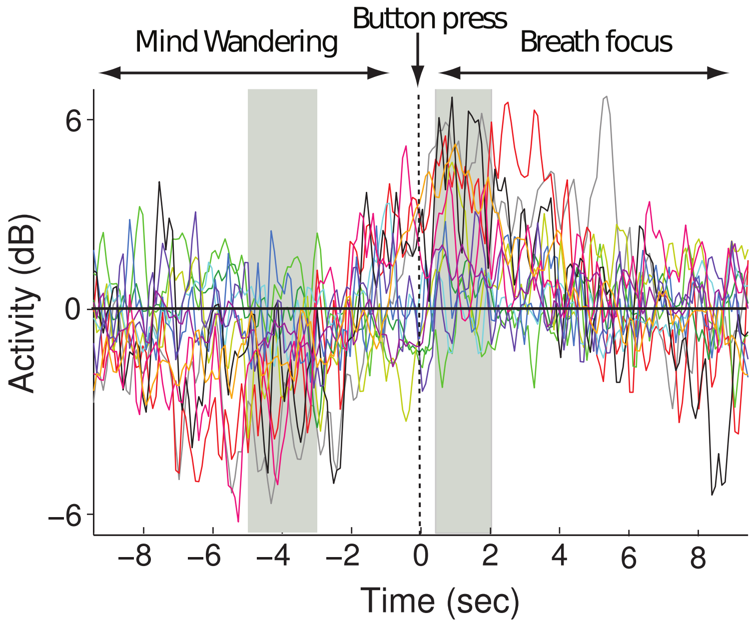


Figure 3.3: Variation of alpha minus theta power over the 20-second epochs centered on meta-conscious events. Difference of activity between log-power alpha (9-11Hz) and theta (4-7Hz) waves at electrode Oz for each of the 12 subjects (the mean difference value is removed for each subject so as to remove any offset on the ordinate axis). This plot indicates significant variation in theta and alpha power (greyed regions p<0.05 after correction for multiple comparisons and removal of regions spanning less than 100 ms).

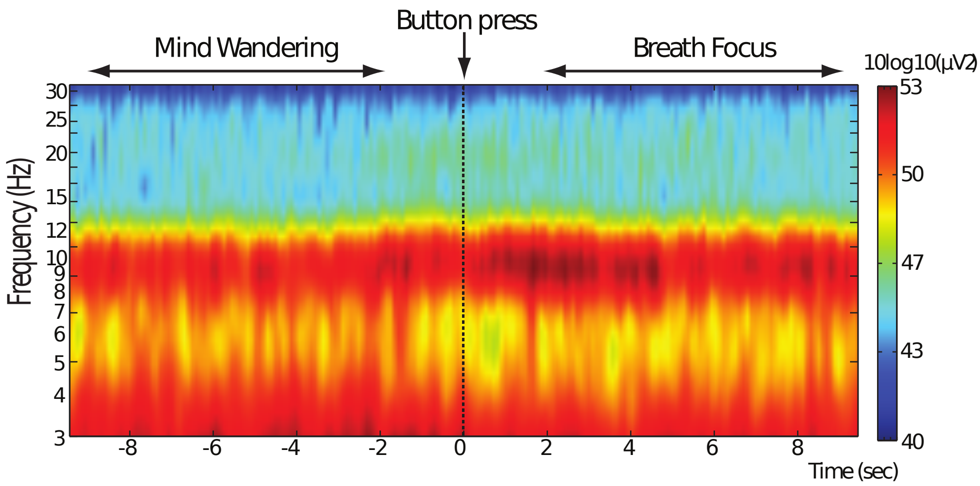


Figure 3.4: Time frequency decomposition of transition from mind wandering to breath focus at electrode site Oz, including only the 6 subjects that did not report drowsiness during the experiment.

Note that the alpha peak frequency could not be found for one of the 12 subjects so we computed statistics using 11 subjects only. Bootstrap statistics revealed significant difference between the central W2 window and the flanking W1 and W3 windows (W1 versus W2, $p<0.0005$, df=10; W3 versus W2, $p<0.002$, df=10) but not between W1 and W3.

3.3.2 Stimulus evoked activity during mind wandering and breath focus

We first tested if the attentional state affected grand average ERPs of the auditory stimuli in the passive oddball paradigm. We observed that the ERP positive component at about 200 ms after stimulus presentation (P2) is significantly higher over fronto-central sites from 180 to 280 ms during mind wandering than during breath focus for both standard and oddball stimuli (figure 3.5). We did not observe any significant interaction between mental state and type of stimuli in this latency range. However, we did observe such an interaction at earlier latencies.

We found a significant effect of the type of stimulus - oddball or standard - on the amplitude of the early ERP negative component between 90 and 120 ms after stimulus onset (figure 3.6). After presentation of an oddball stimulus the ERP is significantly more negative over frontal and temporal regions than after presentation of a standard stimulus both in the breath focus and mind wandering conditions (figure 3.6 3C and 3D). This increased negativity for oddball is usually termed mismatch negativity (Naatanen, Paavilainen et al. 2007). The mismatch negativity (MMN) was larger during breath focus compared to mind wandering over the right frontal region (figure 3.6. 3E).

We then investigated event-related activity using time-frequency decompositions. The event-related spectral perturbation plot reveals increased theta band power (4-7Hz) and decreased high alpha (10-14 Hz) and high beta (20-25Hz) band power after stimulus presentation (figure 3.7). In general, statistical inference testing between the mind wandering and the breath focus state returned a lower p-value for standard stimuli compared to oddball stimuli – it might be a matter of number of observations since there was, on average, five times more trials for standard than for oddball stimuli. From 100 to 300 ms after standard auditory stimuli presentation, theta (4-7 Hz) power was significantly higher on frontal sites when subjects were mind wandering compared to when they were focusing on their breath. Delta (2-3.5 Hz) power 200 to 350 ms after standard auditory stimulation follows the same trend and we also observed a significant power increase for oddball stimuli at occipital and frontal sites.

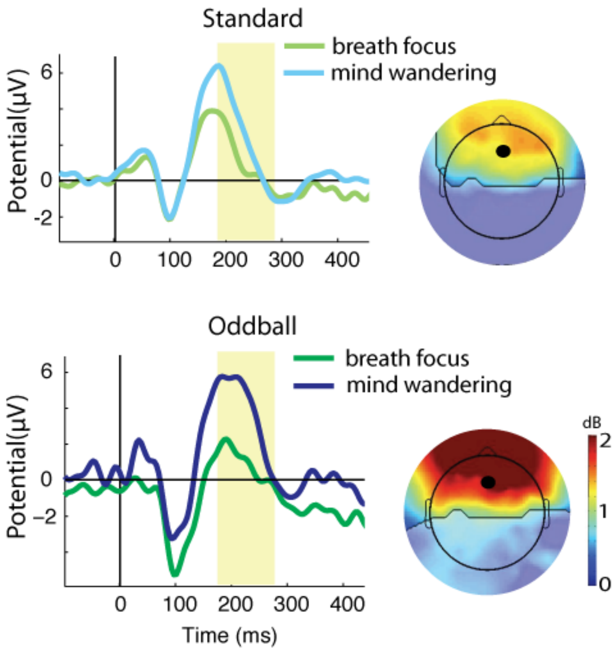


Figure 3.5: Effect of the attentional state on the grand-average ERP for oddball and standard stimuli. A,B: ERP at electrode site Fz for the mind wandering and the breath focus state for standard (A) and oddball (B) stimuli. The shaded area surrounding each curve represents the standard error of the mean. C, D: Topographical maps of the average ERP difference between mind wandering and breath focus for standard (C) and oddball (D) stimuli from 180 to 280ms after stimuli presentation (corresponding to the yellow highlighted region on the ERP plots). Non-significant areas are grayed out in topographic maps and the black dot indicates the position of electrode Fz.

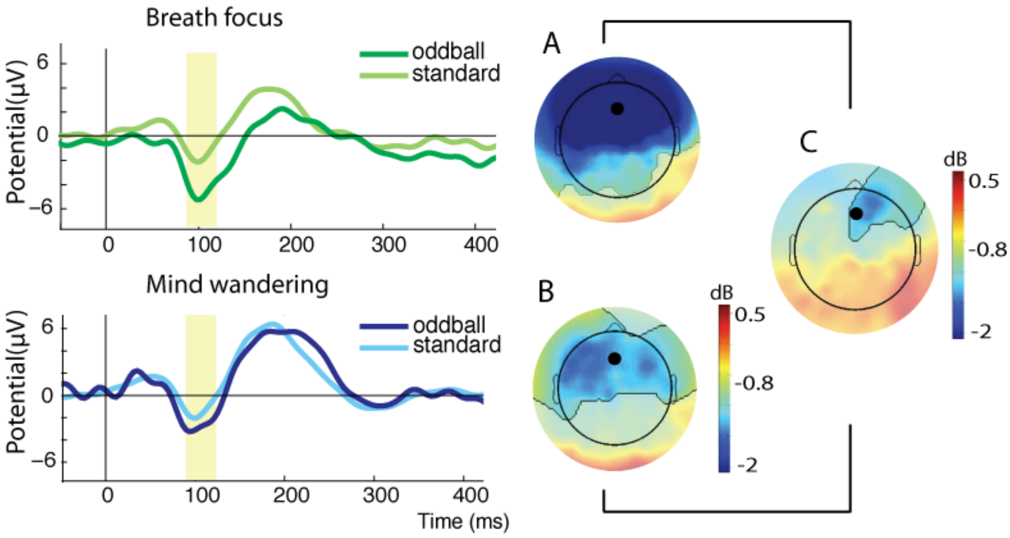


Figure 3.6: Mismatch negativity during the mind wandering and breath focus states. A, B: grand-averaged ERP to standard and oddball stimuli for the breath focus and mind wandering state. As in figure 1, the shaded area surrounding each curve represents the standard error of the mean. C, D: Topographical difference maps between the mean ERPs to oddball and standard stimuli (Mismatch negativity MMN) for the breath focus and the mind wandering state. E: Topographical difference map between MMN maps in breath focus and mind wandering condition (map C – map D). Non-significant areas are grayed out on the topographic maps and the black dot indicates the position of electrode Fz.

High beta (20-25Hz) power from 100 to 300 ms after standard stimuli presentation is significantly higher on parieto-occipital sites during mind wandering compared to during breath focus. Interestingly, despite large high alpha (10-14 Hz) evoked power to both standard and oddball stimuli, we did not observe any significant effect of the attentional state on the ERSP in this frequency band.

We also tested for difference of ERSP between standard and oddball stimuli during both the mind wandering and the breath focus states. Only beta band power from 100 ms to 300 ms after stimulus presentation differed significantly, being lower for oddball stimuli . This effect was not significantly different between the mind wandering and the breath focus states. Although figure 3.7 seems to show a decrease in the 10-15Hz frequency band around 220-380ms after stimulus presentation, we did not find any significant difference for that frequency window between either standard and oddball stimuli or mind wandering and breath focus conditions.

3.4 Discussion

Our study aimed at characterizing the neural correlates of spontaneous and task-unrelated mental activity (i.e. mind-wandering) and its effect on sensory processing. Compared to a breath-focus mental state, we have shown that mind wandering is characterized by a power amplitude increase in the theta frequency band and a power amplitude decrease in the alpha and beta frequency bands. We also showed that, during mind wandering, standard auditory stimuli induce a higher power in the theta and delta frequency band over parieto-occipital regions and higher power in the high beta frequency band over frontal regions. The study of mean evoked related potentials revealed that the amplitude of the P2 positive ERP component is larger during mind wandering than during breath focus and that the MMN is of smaller amplitude during mind wandering than during breath focus. Taken together these results establish a strong link between the subjects' internal experience – mind wandering or breath focus – and distinct neural correlates.

3.4.1 Brain states fluctuation at rest and spontaneous reports of mind wandering

The difference in EEG activity between mind wandering and breath focus is consistent with the Laufs et al. (2006) EEG-fMRI study showing that spontaneous EEG alternates between two states at rest. Our study refines Laufs' results by showing that the low frequencies (theta-delta) and high frequencies (alpha-beta) changes he observed may

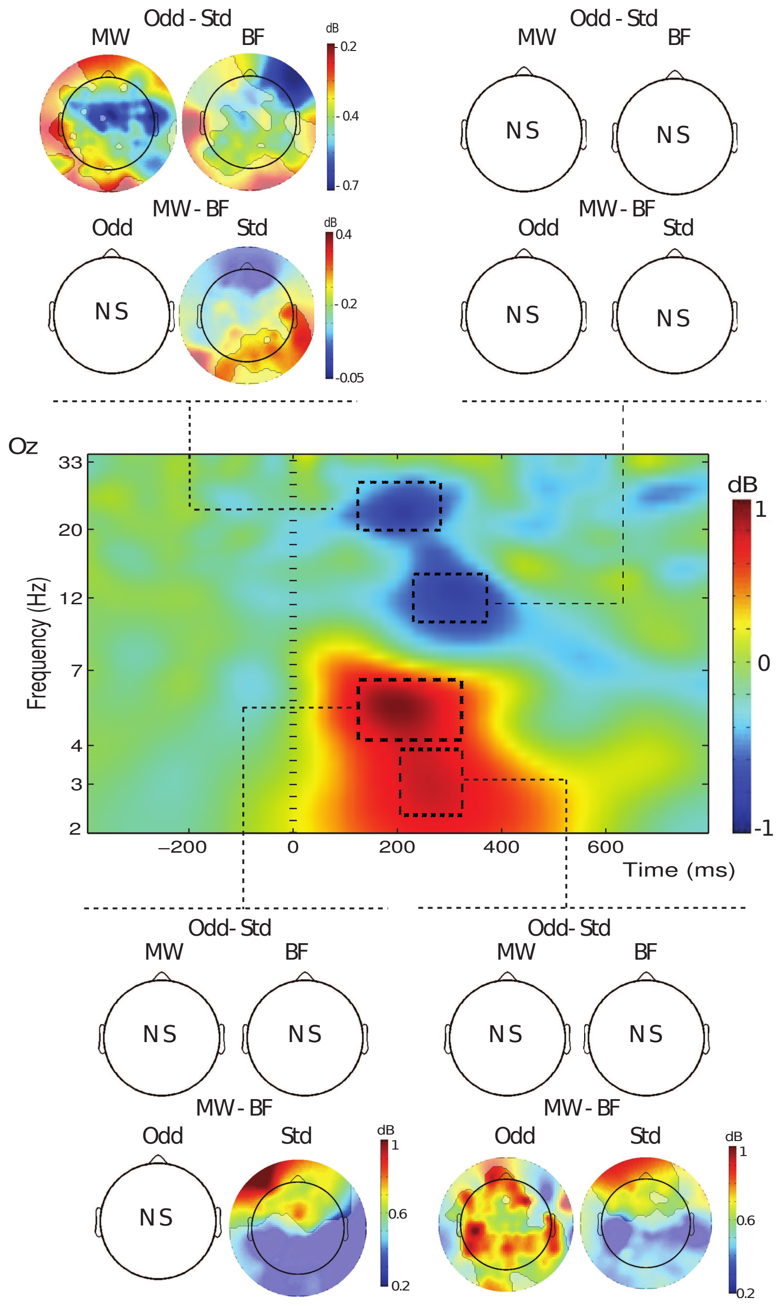


Figure 3.7: Effect of attentional state and type of stimulus on event related spectral perturbation. The central panel indicates the grand-average ERSP at electrode Oz averaged over both oddball (Odd) and standard (Std) stimuli and over both the mind wandering (MW) and the breath focus (BF) state. Topographical maps of power difference between oddball and standard stimuli are shown for the mind wandering and breath focus condition as well as topographical maps of power differences between mind-wandering and breath focus conditions for oddball and standard stimuli. Shaded areas represent non-significant regions. Scalp maps for which there is no significant electrodes are indicated using a blank map with the sign ns. The black dot represents electrode Oz.

be associated to a transition between a state of concentration on processing external stimuli and involuntary mind wandering. Our EEG study further confirms that when subjects are engaged in a task, the brain can spontaneously shift into another alertness mode, which is most likely mind wandering. fMRI bold signal during the resting state shows spontaneous fluctuations between a “task positive” network comprising brain areas activated during attention-demanding tasks and a “task negative” (or “default” network being activated during rest and deactivated during these tasks (Fox et al., 2005). Preceding reports of mind wandering, Christoff et al. (2009) found increased BOLD activity both in the default network (precuneus, ventral anterior cingulate cortex and temporoparietal junction) and in the frontal executive network. This result is consistent with an fMRI study showing increased amount of mind wandering linked to increased amount of activity in the task negative network (Mason et al., 2007). Continuous increase of BOLD activity in the occipital, frontal and temporal parts of the defaults network is also found during the transition from eyes-closed wakefulness to sleep (Olbrich et al., 2009). The higher occipito-parietal theta and fronto-central delta during mind wandering could thus be related to increased BOLD activity in these areas.

We also observed a delta power increase during mind wandering, an increase that we believe could be linked to decreased alertness. Spontaneous delta power increase has been linked to decreased performance during cognitive processing (Harmony et al., 1996). Spontaneous delta power increase has also been associated with decreased level of alertness in various experimental setups (Makeig and Inlow, 1993; De Gennaro et al., 2001; Caldwell et al., 2003). Moreover, as reviewed by Laufs et al. (2006) and shown in this report, delta power increase is associated with alpha power decrease, which has been associated with low stages of vigilance (Loomis et al., 1937; Roth, 1961). Note that 6 of the 12 subjects reported some level of drowsiness during the experiment, but as we have shown in figure 3.4 this does not seem to have affected our data. The meta-consciousness event allowing the transition from the mind wandering to breath focus is finally marked by a transient increase of about 1Hz of the alpha peak frequency and also by a more long lasting increase in alpha power. Re-directing the attention to the task requires increase working memory activity and that has been shown to be correlated with alpha power increase (Jensen et al., 2002), a power increase that may index re-activation of thalamo-cortical pathways (Schreckenberger et al., 2004). The alpha-peak frequency increase may also be a marker of the attentional switch between mind wandering and the focused task since Angelakis et al. (2004) suggests that increase of peak alpha frequency might represent a state of "cognitive preparedness".

Interestingly, Hasenkamp et al. (2011) have adapted our protocol in an fMRI study, using meditation practitioners as subjects. Participants in Hasenkamp et al. (2011) study had to do a 20 minutes meditation period within the scanner, focusing their attention on the breath and pressing a button when noticing that their mind has gone completely off the breath. These authors report activity of brain regions implicated in the default mode network (posterior cingulate cortex, medial PFC, posterior parieto-temporal cortex and parahippocampal gyrus) during mind wandering while the period of awareness of mind wandering is associated with activation of brain areas usually involved in the detection of environmentally salient external events, that is bilateral anterior insula and dorsal ACC. The following shift to desengage from mind wandering and redirect the attention on the breath is characterized by activation of the frontoparietal executive network. During sustained attention to the breath, there is persistence of dorsolateral prefrontal cortex activity. Thus, Hasenkamp et al. (2011)' s study supports the existence of shifts in activity between areas of the default mode and attentional networks. Additional combined EEG-fMRI studies would be needed to establish a clearer link between EEG and BOLD signature of the mind wandering state and its relation to the default mode network, in particular regarding localization of the neuronal sources of the EEG rhythm correlated with the BOLD signal.

3.4.2 MMN, attention, alertness, and mind wandering

The study of evoked related potential shows an increased negativity at frontal electrode sites for the ERP of oddball compared to the ERP of standard stimuli from 90 to 120 ms after stimulus presentation. This result corresponds to the mismatch negativity (MMN) usually described as negative brain response to the sensory detection of a sudden change in the flux of auditory perception (Näätänen et al., 2007). The MMN typically occurs approximately 100 to 150 ms after stimulus presentation and is centered on fronto-central electrodes sites (Näätänen et al., 2007). The amplitude of the MMN is modulated by the direction of the subject's attention (Sabri et al., 2006), and is larger when the attention of the subject is directed toward the auditory stimuli (Alain and Woods, 1997). Our results show the MMN amplitude is lower during mind wandering compared to breath focus, which suggest a disengagement of the attention from stimuli processing during mind wandering. The reduction of the MMN is also characteristic of drowsiness and the early sleep stages (Sallinen and Lyytinen, 1997; Nittono et al., 2001) , which supports the idea that the mind wandering state is associated with decreased vigilance. This also suggests that mind wandering may share common traits with the decreased alertness characterizing the transition from wake to sleep (Sabri et al., 2003). Note that we did not observe in our data the late negativity at about 300 ms after stimulus presentation that accompanies advanced states of drowsiness leading to sleep or sleep itself (Winter et al., 1995; Campbell and Colrain, 2002) . This suggests that our subjects were not deeply drowsy. Mind wandering could thus correspond to an early state of drowsiness of decreased alertness and vigilance.

3.4.3 Late stimulus evoked activity and disengagement of attention from stimuli processing during mind wandering

ERPs analysis also reveals that the amplitude of the positive component at about 200 ms (P2) is larger during mind wandering than during breath focus. This effect is also present, although to a lesser extent, in Cahn (2007) who found a P2 component larger for distracting stimuli when subjects were actively reactivating autobiographical memories – which may be considered similar to mind wandering - compared to when they were practicing meditation. Increase of the P2 component to auditory stimulus has also been associated with the disengagement of subjects' attention toward stimuli (Naatanen and Picton 1987) and is also characteristic of the sleep onset period (Campbell and Colrain, 2002). Again, this result is consistent with attentional disengagement toward stimuli processing during mind wandering. We did not observe a P300 ERP component associated with the presentation of the rare stimuli in our passive auditory oddball task. P300 is best observed in active experimental design where the subjects have to respond to rare targets and is usually hardly visible in passive oddball paradigms (Cahn and Polich, 2009). Using an active task, Smallwood et al. (2008) showed a reduction of the P300 ERP during mind wandering. Consistent with our MMN and P2 results, Smallwood et al. (2008) result suggest a disengagement of attention towards external stimuli processing. The study of ERSP is harder to interpret since it is rarely presented in literature. Increased evoked theta frequency over frontal regions may be related to increased autobiographical memory engagement during mind wandering (Jensen et al., 2002; Onton et al., 2005) . Note that the ERP differential scalp maps from 180 to 280 ms were similar to the theta frequency maps with strong changes over occipital regions. The ERP is a complex combination of stimulus-locked phase synchronization and spectral amplitude increase (Makeig et al., 2002; Delorme et al., 2007). We tested if ERP and ERSP activities were linked by computing the correlation between the ERSP activity and the ERP at electrode site Fz for the evoked delta, theta, alpha and beta frequency band activity shown in figure 3.5. We did not find any correlation between the early ERP negative component between 90 and 120 ms after stimulus onset and any of the ERSP components. However, when pooling data for both types of stimulus and both attentional states, we did find a positive correlation ($p<0.001$; $df=47$; paired t-test) between the evoked delta (2.5 to 3.5Hz) and high alpha (10-14Hz) activity 100 to 300 ms after stimulus onset and the late ERP positive component at 180 to 280 ms. This indicates that both the late ERP complex and delta ERSP activity may index similar processes in our passive auditory oddball task.

In conclusion about this study, we have shown the neurophysiologic markers of mind wandering. Based only on subjective reports about mind wandering, we have established that two different attentional states correspond to two distinct brain states underlying different modes of sensory processing. Our results suggest that mind wandering correspond to a state of rest, a state of low vigilance where stimulus evoked responses are reduced. This study is one of the first event-related neuroimaging study to rely only on behavioral responses based on pure – not stimulus induced - introspective subjective reports. It further demonstrates that approaches based on subjective experience are possible in neuroscience yet argues for the need of a more fine-grained taxonomy of private mental states.

The next chapter will present our preliminary work on the phenomenology of mind wandering.

Chapter 4

Phenomenological study of mind wandering

Contents

The methodology we use in our first study on mind wandering (chapter 3) allow assessing frequency of occurence of mind wandering episodes but not provide information on their content. This chapter presents our preliminary work to include phenomenological data in future mind wandering studies. The first section present phenomenological protocols integrated in neuroimaging studies and the second section will present our preliminary work using the explicitation interview technique. This chapter aims more at introducing our exploration of methodological leads rather than at presenting well-established results. We thanks Claire Petitmengin for her help and support in the training of the explicitation interview technique and its application to the study of mind wandering.

4.1 Explicitation interview

The main goal of an explicitation interview is not to retrieve the semantic content of an experience but the inner structures, or gesture, of that experience.

The main steps in a standard explicitation interview are described in Petitmengin (2006) and briefly detailed below:

- The first step consists in finding a particular situation to be elicited, which is generally a past experience.
- The second step consists in questioning the interviewee about the sensory characteristics of the situation to guide him/her into a state of evocation involving the interviewee' s autonoetic consciousness [1] of the event.
- A third step consist in distinguishing between general descriptions and descriptions of inner actions and sensations. During the interview, the questions are more directed towards the "how" than the "what" of the experience, in order to help the interviewee focus more on describing the structure of the experience rather than its semantic content.

Following training in the explicitation interview methods with Claire Petitmengin, I applied it to the study of the inner gesture accompanying a mind wandering episode.

4.1.1 Interview setting

We chose to use again the breath counting task presented in chapter 3: the subject sit at a table and has to count his breaths from 1 to 10 in a loop, with his eyes closed. Whenever he/she realizes that he/she is not doing the task anymore, meaning that he/she does not know the next count or stopped counting, he/she has to signal it by knocking on the table. The explicitation interview then starts. With the agreement of the subject, an audio recording is made of the interview.

[1] developed in the human memory literature, the concept of autonoeitic consciousness refers to the capacity of both mentally represent and becoming aware of our subjective experiences in the past, present or future (Tulving, 1985; Wheeler et al., 1997)

4.1.2 Guidelines

To help focus the interview and questions as to which experience to explore, preliminaries explicitation interviews were realized and 3 key moments of a mind wandering experience were identified and for each, potential interesting directions to explore during the interview

- *the concentration on the breath:* the concentrative process (how does the subject to focus) and the state of concentration (what was the attention directed to, was there a feeling of the breathing, or any other physical sensation).
- *the mind wandering episode:* the appearance of the thoughts (its localization, distance, size, colours), the trigger of the drift (was it from an external or internal source) and the diminution of the attention turned toward the breathing (what was the importance given to the thought compared to the breathing).
- *the realization of the mind-wandering occurrence:* determination of its timing, (was it immediate or progressive ?).

4.1.3 Analysis of an explicitation interview

Analysis of the data collected during an explicitation interview starts with the transcription of the interview. The transcript is then read and anecdotal contents and general description are put aside while the information regarding the experience itself is emphasized. Then the different events marking the different stages of the experience are identified. This process allows to determine the diachronic structure, that is the temporal unfolding of the experience, with its successive stages. As a second step, experiences characterizing each stages are identified: the sensations, quality of attention, emotion, etc. accompanying each stages. These experiences are called experiential categories and they allow defining the synchronic structure of each phase, that is, its non-temporal dimension corresponding to the subject's experience. Finally, for each subject, an individual model of the structure of the mind wandering episode is created. The observation of invariants across the different models allows constructing a general representation of the experience of mind wandering.

4.1.4 Preliminary results: diachronic structure of a mind wandering experience

We will present here the analysis of data collected with 4 subjects. One subject did the interview twice, with two different mind wandering episodes. Appendix A is an example of the transcription of an interview, in french.

Here we will focus on the mind-wandering episodes from their onset until their end, and present their diachronic structure.

As mentioned earlier, before the occurrence of mind wandering all subjects were counting their breath, seating with their eyes closed.

Based on the descriptions, we identified the different phases of a mind-wandering event: (1) the apparition of a distractor, (2) the attention starting shifting toward this distractor, (3) the attentional lapse and (4) the detection of a change or conflict, which terminates mind wandering episodes. All interviewees described phases 1, 3 and 4. One out of the 4 interviewees did not described phase 2. Still based on the subjects' description we identified experiential categories that were present throughout the different phases: the direction of the attention and the mental content. Below we present our principal findings. Interviews were realized in french language and we translated into english the excerpts included here.

1. **Apparition of a distractor**

    - *Mental content:* among the experience associated with the breath counting task, a distractor appears. It can either be mental images, body sensation or physical stimulation from the external environment. Inner dialog can be present.
    - *The direction of attention*: at this stage, the interviewees report that their attention is still primarily focused on the breath counting task.

    "At first I can keep track of the count, in between two thoughts that are interrupting the process. " M.R1
    "I paid attention to this noise, but I kept on counting " G.B.J
    "I was on my 3rd cycle counting and I started to, I don't know how to say, to feel an oppressive feeling of having the eyes closed. It came progressively" M.R2

2. **The attention start shifting**

    - *Mental content:* the distractor is more and more present and its characteristics are changing. In the case of a mental image, it may start moving, a sound might be perceived louder, inner voices dialogues might occur.
      "ideas come to life .. it is now images in movement. Instead of images that overlap, you can think of a movie that unfold." M.R1

"I don't know who's voice .. the voice of someone. I heard it inside me, as if the sound told me 'Hi, I'm going to bother you a little bit.'" G.B.J

- *The direction of attention*: the attention is now turning more towards the distractor than the counting task.

  "all that noise around, like the building work, I stopped hearing it. I was more focused on the noise I was making myself [...] I started focusing only on just the act of breathing and not counting anymore" H.M
  "At 8 60% [of my attention was] on the count and 40% outside, 9 too but I feel that 11 was more more outside, I increased the percentage of attention toward the noise outside" G.B.J
  "The impression of having a counter before me and after a while I lose the focus on the counter and I end up watching something that is around .. my thoughts are around" M.R1

3. **Attentional lapse**

- *Mental content:* the phenomenal contents varies wildly in that phase. 2 of the 4 subjects reported experiencing a "blank". The others got absorbed in the experience of the distractor.

  "It is a time of blank, this is a time where it is empty." M.R2
  "the colours [of the mental images] came once I lost track of everything else" M.R1
  "then I think at number 10... I don't remember number 10, I don't see myself counting the 10" G.B.J

- *The direction of attention:* the attention was entirely captured by the distractor. Based on the data we collected, it was not possible to retrieve the description of a specific movement of the attention corresponding to this phase.

  "the impression of a total slip. The numbers [from the breath counting task] were gone" M.R1
  "I had forgotten I was here and I was only on my breathing" H.M

4. **Detection of a change: end of mind wandering**

- *Mental content:* the subjects become conscious of a change in their attitude, body sensations or of a conflict taking place between what they are doing and what they are supposed to do.

- *The direction of attention:* subjects tend to report that their attention is "going back to themselves"

"When I felt that I was not breathing deeply anymore, I opened the eyes. I realized that I was not doing what I should be doing." M.R1

"I came back to the task without realizing at first that I had drifted away and when I started counting again I had the impression that something was wrong. In the unfolding of my logic, there's something missing. So I wondered: is it that I went from '5' to '7', did I though of saying the '6'? .. I realize that there is a moment where I was not really present." M.R2

"After, I said '12' and suddenly I thought: 'it's nonsense G., you must come back to 1 '" G.B.J

4.1.5 Discussion

Although these results are preliminary, they provide for the first time to our knowledge an account of the different phases structuring a mind-wandering event, based on pure phenomenal descriptions. The main components of a mind wandering episode are: the apparition of a distractor, the attention starting shifting toward this distractor and the attentional lapse. Detection of a change or conflict terminates mind wandering episodes.

We have seen that in the course of a mind-wandering episode, the phenomenal characteristics of the distracting stimulus evolve. Mental images may contain colour and be animated, an inner voice may be heard etc. Although these are only a few characteristics collected over a limited number of subjects, it already highlights the large variety of experiences from subject to subject and from one episode of mind wandering to another. Note that one of the subject gave a very complete description of the mental images and the changing occurring to them as he was becoming less and less focus on the task, so recollection without awareness of not performing the task at hand, is possible.

What could be the utility of this approach to the study of mind wandering ? First, we have to confirm our preliminary diachronic analysis by confronting it to the experience of more subjects, to ensure that we have correctly identified it. Then with more data we could also analyze the subject's report depending on the class of mind wandering episode. For example we could have classes of mind wandering corresponding to the type of distractors "mental images", "external sound" and "body sensation" and analyze the diachronic and synchronic structure of the mind wandering event for each class. Another possibility could be to group interview data according to the characteristics of the phase "attentional lapses", depending on whether the subject is reporting "a blank" or explicit mental content.

We believe such data would contribute to our knowledge of the inner structures underlying the so familiar mind wandering experience and would also opens news ways of refining its study in neuroimaging experiment.

4.2 Methodology for online collection of phenomenological data

The explicitation interview is obviously not suited for being used directly in neuroimaging experiments. To be able to correlate the brain EEG activity with online reports of the characteristic of mind wandering episodes, we designed questionnaires that the subject could fill in an online fashion during the experiment.

This questionnaire has been designed in collaboration with Romain Grandchamp and we also wish to thanks Claire Petitmengin for her valuable feedback on the questionnaire structure. The task for the subjects was again to perform the breath counting task (see chapter 3). Subjects were facing a computer screen and holding a mouse in their right hand. Upon realizing they were mind wandering, they had to press the mouse left button and the questionnaire screen was then presented. If they mistakenly pressed the left mouse button - without having experienced mind wandering - subjects could press on the mouse right button to exit the questionnaire. Both our subjects were meditation practitioners, and thus particularly sensitive to the detection of mind wandering episodes. They were explicitely told to signal both the occurrences of simultaneous thoughts in parallel to the execution of the task and the moments where they had lost the count of their breaths. The questionnaire, shown in figure 4.1, is composed of eleven questions with multiple choice. For each question, there is a single answer possible. Before starting the experiment subjects had time to familiarize with the questionnaire, so they can respond to it quickly during the experiment.

1. **Involvement in the task :** this question relates to how much the subject was involved in the breath counting task during the mind wandering. We made here the distinction between three types of possibilities:

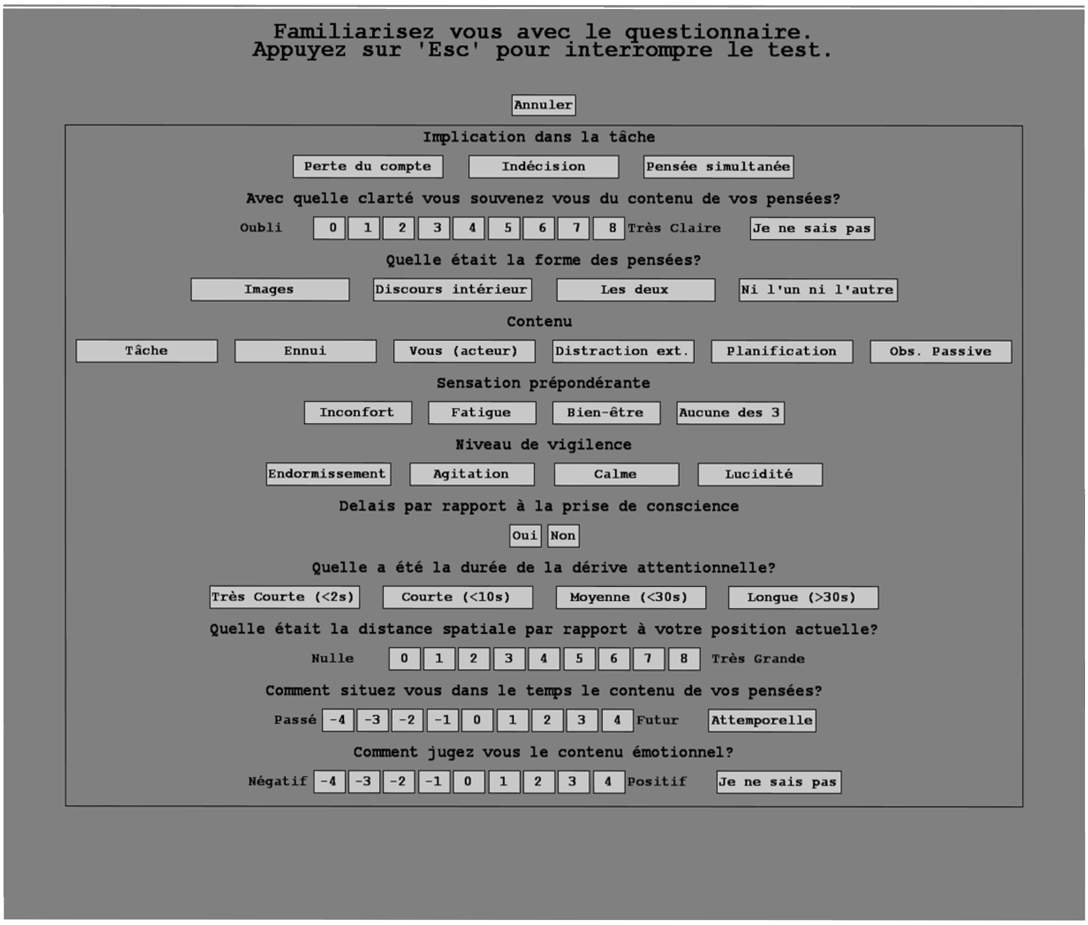


Figure 4.1: Screenshot of the questionnaire for the online evaluation of the characteristics of a mind wandering episode

- *lost track of the count :* the subject did not know anymore the count of his breaths
- *uncertainty:* the subject was hesitating between two numbers when counting
- *simultaneous thoughts*: the subject did not lost track of the count, but experienced simultaneous thoughts that he could follow without disturbing the primary task

2. **How clearly do you remember of the contents of the thoughts:** this question relates to the capacity of the subject to remember his experiences during the mind wandering episode. The answer must be provided on a scale of *I forgot (0)* to *Very clearly (8)*. An additional button *I don't know* gave the possibility for the subject to indicate his uncertainty.

3. **What was the form of the thoughts ?:** this question aims at characterizing the phenomenal content of the thoughts during mind wandering. The following choices were given:

   - *images*
   - *inner dialogue*
   - *both images and inner dialogue*
   - *neither one nor the other*

4. **Content of the thoughts :** what were the thoughts about ?

   - *the task :* the subject was thinking about the task
   - *boredom*
   - *yourself as a protagonist :* the subject thoughts of future or past situations in which he sees himself as a protagonist
   - *an external distractor:* an external sound or stimulation disturbed the subject
   - *plannification:* the subject was making plans for the future
   - *passive observation:* the subject was not taking any active role in the situations he thought about - as if watching a scene from a movie.

5. **Predominant feeling :** what was the general state of the subject ?

   - *discomfort:* the subject experienced physical discomfort
   - *tiredness:* the subject was getting tired

- *well being:* the subject was feeling well
- *none of the three*

6. **Vigilance level :**
   - *drowsy:* the subject was getting sleepy
   - *agitated:* the subject was restless (wanting to move etc..)
   - *calm:* the subject was calm
   - *lucid:* the subject was very aware of his sensation and mental contents

7. **Time-lag between the experience of mind wandering and the button press ? :** this questions aims at identifying situations in which there is a time-lag between the termination of a mind wandering event and the realization of the subject that he has been mind wandering.
   - *Yes*
   - *No*

8. **Duration of the mind wandering episode:**
   - *Very short (less than 2 secondes)*
   - *Short (less than 10 secondes)*
   - *Average (less than 30 secondes)*
   - *Long (more than 30 secondes)*

9. **Spatial distance with regard to your current position ? :** this question attempts to characterize the spatial projection during the mind wandering, whether the subject thought of events taking place in the lab or in far away places. Answers were given on a scale from *null (0)* (the setting of the thought content was the experimental room) to *very far (8)*.

10. **How do you situate in time the content of your thoughts ?:** this question taps into the temporality of the thought content. Answers were given on a scale from *Far in the past (-4)* to *Far in the future (4)*. Zero indicated the present. An additional button *Non temporal* was provided to indicate thoughts that were not marked by a distinctive temporality.

11. **How do you judge the emotional content of your thoughts ?:** Answers were given on a scale from *Negative (-4)* to *Positive (4)*. Zero indicated neutral emotion. An additional button *I don't know* was also provided.

4.3 Preliminary results

The questionnaire has been used in a EEG/eyetracking experiment aiming at correlating physiological signal with the content characteristics of mind wandering occurrences. In addition, in this experiment, we also wanted to assess the reliability of the results in a same subject across sessions. Thus two subjects undertook the experiment 11 times over a month (one session of the experiment itself lasted 20 minutes). Data from the eyetracking recording have been analyzed and presented in Grandchamp et al. (2011) and the EEG data is currently been analyzed. We present below preliminary accounts for the responses on the questionnaire.

4.3.1 Frequency of mind wandering

Over the 11 sessions, we collected 415 and 413 occurrences of mind wandering for subject 1 and 2 respectively, which makes about 38 mind wandering episodes for each subject over the 20 minutes of a session (about 1.8 mind wandering event per minute).

4.3.2 Analysis of the answers

Figure 4.2 shows the answers of each subject to the questionnaire across the sessions. We observe that for both subject the majority of mind wandering reports concerned the occurrence of thoughts simultaneous to the execution of the breath counting task. Most of the time there was no time lag between the occurence of the mind wandering event and its report by the subject. The majority of mind wandering episode lasted for about 10 secondes. Regarding thoughts content, for both subjects most thoughts involved both mental images and inner dialogue and where related to events taking place in the close environment of the subjects. The thoughts content concerned in majority thoughts relative to the task or the passive observation of a situation. The thoughts were almost never about events taking place very far in the past or in very far in the futur. Most had temporal quality close to the present time of the subject or did not have any distinctive temporal characteristic. The emotional content was mostly either slightly negative or neutral. The subjects level of vigilance was mostly either normal (calm) or lower than normal (drowsiness). Subjects differ in the quality of feelings they report, subject 1 experiencing more discomfort than subject 2, while subject 2 was ore tired than subject 1.

In overall these preliminary results inform about the characteristics of mind wandering of 2 subjects during the breath counting task, in the conditions of a simultaneous EEG-eyetracking experiment. Of course more subjects would be needed before we are able to draw general conclusions about the characteristics of mind wandering. The data concerning the vigilance state will also be very helpful in the analysis of physiological data.

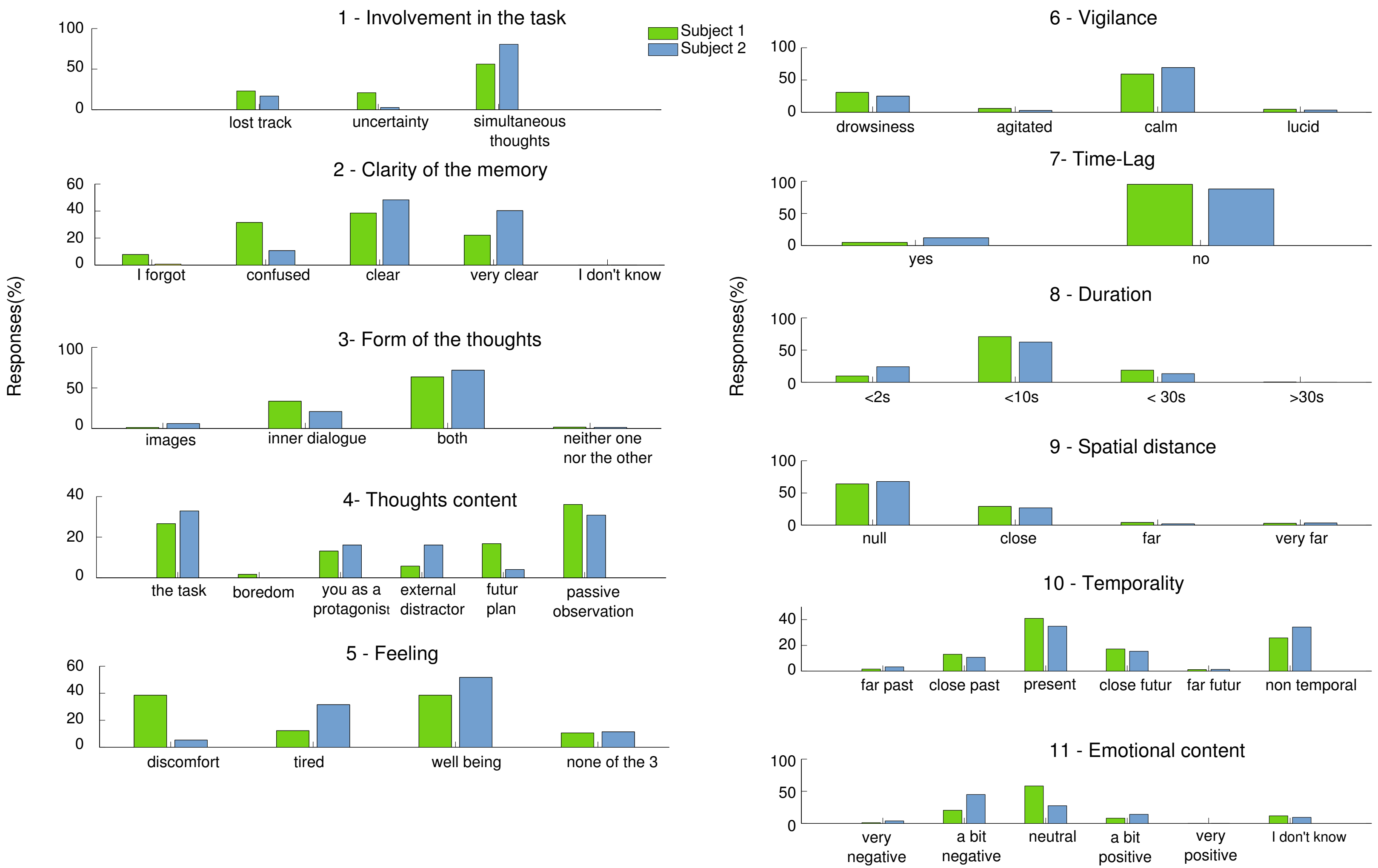


Figure 4.2: Quantification of the answers to the questionnaire across the total number of mind wandering events reported by each subjects.

4.4 Possible improvements and perspectives

There are potential improvements that can be done to the actual questionnaire. For a future utilisation we plan to remove the scales and replace them by qualitative variables to facilitate data processing and give more homogeneity to the questionnaire. It also took a certain time for the subjects to familiarize enough with the questionnaire and the meaning of the questions to answer them accurately. In our preliminary data subjects were meditation practitioners that were already sensible of the different characteristics their thoughts could take. For subjects that are not meditators it might be more difficult at first to grasp the characteristics of the content of their thoughts. In this case it might be useful to consider giving an examplar of the questionnaire to meditation-naive subjects a few days before the experiment to allow them to familiarize with the process of paying attention to their mind wandering thoughts and especially to the characteristics that are assessed in the questionnaire.

In another experiment we adapted the questionnaire for using it in the context of an fMRI study, with a response pad with only 6 possible keys. For that purposed we simplified it and used pictogrammes, as shown in figure 4.3. The task was a classical Sternberg working memory task, where subjects had to memorize strings of letter and indicate after a 20 secondes retention interval wether a given letter was present or not in the string. Subjects were then probed with a questionnaire to indicate the main content of their thoughts during the retetntion interval. There was 6 possible answers: *button 1:* thinking of the task, *i.e.* . rehearsing the letters (top left figure), *button 2:* thoughts that were related to the task (top right figure), *button 3 :* thoughts about external distractors, such as the sound of the MRI scanner (middle left figure), *button 4:* mind wandering, *i.e.* . thinking of something not related to the task or to a stimulus of a current environment (middle right figure), *button 5:* feeling drowsy (bottom left figure) and *button 6:* having short periods of "micro sleep" as it can happen when lying in the scanner (bottom right figure).

We believe the use of online questionnaires for the study of mind wandering in neuroimaging will develop in the coming years and contribute to better analysis and understanding of the mechanismes of mind wandering.

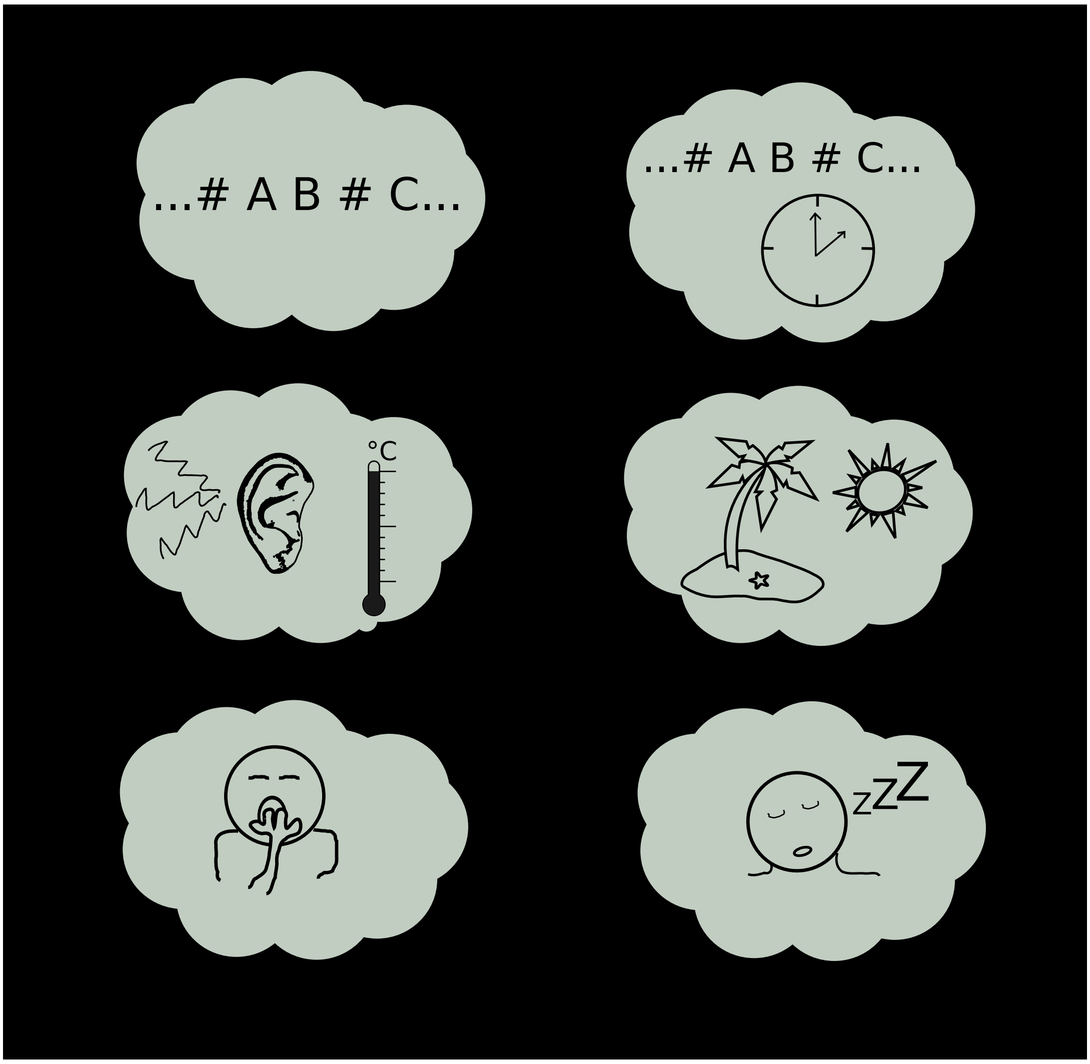


Figure 4.3: The questionnaire designed for being use in fMRI during a Sternberg task. Top left figure: thinking of the task ; top right figure : task-related thoughts; middle left figure: thinking of external distractors; middle right figure: mind wandering; bottom left figure: drowsiness; bottom right figure: periods of “micro sleep”.

Part III

Meditation

Chapter 5

An introduction to the scientific study of meditation

Contents

In this second part of the manuscript, I turn towards the study of meditation. First I am presenting a state of the art review of the effects of meditation on the body and brain and then I report a study aiming at carefully comparing the brain EEG activity of 3 different meditation traditions, compared to a meditation-naive control group.

But first, I will go more in details about the inscription of meditation in scientific paradigms and the diversity of meditation practices.

5.1 Meditation and its scientific paradigm

Meditation has been the subject of scientific research for about the past 40 years but only started to gain popularity in the late 1990s (see Figure 5.1).

Based on the assumption that different conscious states are accompanied by different neurophysiological states, the neuroscientific approach to meditation focuses on altered sensory, cognitive, and self-awareness experiences. Meditation-induced neurophysiological changes may be of two kinds: changes that occur during meditation practice are referred as state changes, changes which build up over months or years and persist even when the mind is not actively engaged in meditation are referred to as trait changes (Cahn and Polich, 2006).

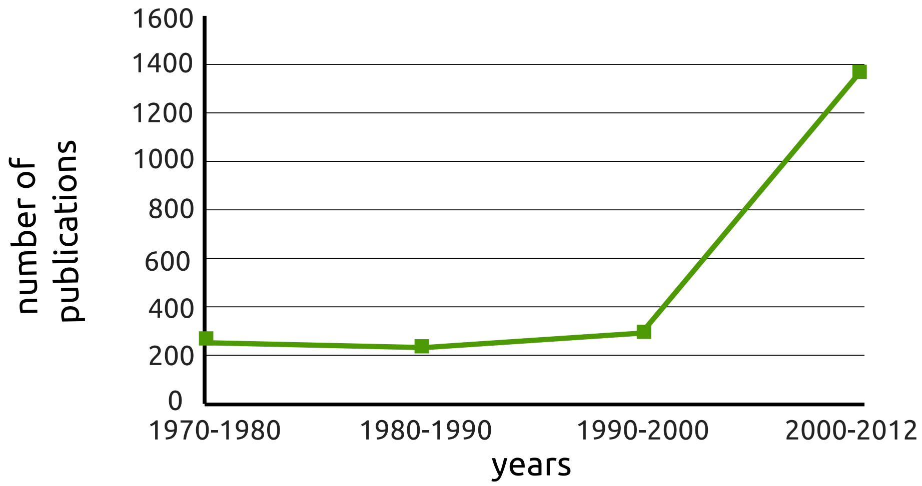


Figure 5.1: Evolution of the numbers of publication having the term "meditation" either in its title or abstract and referenced in PubMed from 1970 to July 2012

5.1.1 A working framework

There are a large number of distinct meditative practices (see5.2), and only recently an operational framework have emerged to facilitate the scientific study of meditation by providing a common ground for an operational definition of the practices (see Bishop et al., 2004; Cahn and Polich, 2006; Lutz et al., 2008b; Josipovic, 2010). Given that self-regulation of attention is a major component that is common among all meditative practices, meditative styles can be classified on a continuum depending on how attentional processes are directed, from focused to unfocused practices (Lutz et al., 2008b). Concentrative - or focused attention — techniques involve continuous sustained attention on a selected object: the object of focus may be breath or body sensations, a subvocal repeated sound or word (mantra), or an imagined mental image. Focused attention meditation requires the narrowing of awareness so that the mind only contains the object of focus. If distraction occurs, such as mind wandering, the practitioner has to shift his attention back to the selected object of meditation. On the other hand of the continuum, mindfulness (unfocused) meditation practices, also called open-monitoring, open awareness or insight meditation, involve the expanding of awareness with no explicit focus (except awareness itself). In open monitoring, practitioners are instructed to allow any thought, feeling, or sensation to arise in consciousness while maintaining a nonreactive awareness to what is being experienced. Mindfulness may be described as sustained awareness aimed at nonreactive and nonattached mental observation, without cognitive or emotional interpretation of the unfolding moment-to-moment experience (Cahn and Polich, 2006; Gunaratana, 2002; Kabat-Zinn, 2003; Lutz et al., 2008b). To this operational framework, we can add "passive" meditation which includes meditation practices marked by the absence of focus and of individual control or effort (Lutz et al., 2007).

In addition to these considerations regarding attentional direction, the affective dimension of the practice can also be taken into account. Indeed many practices include the wish of happiness for others (loving kindness) and/or the wish to relieve other' s suffering (compassion) (Lutz et al., 2008a).

At this point it is important to note that although the criteria exposed above are useful tools for the scientist they are not mutually exclusive in practice. One may start a meditation session by focused attention then switch to open awareness and finally transcending the object of his meditation. Or these different aspects can be reached as one gained experience and training in a meditation practice. For example, as describe in figure 5.1.1, the *Chag-zôg* Tibetan practice of open monitoring starts by a meditation focused on an object before moving towards more and more detachement to finally observe awareness itself.

In the majority of studies at the time being, the instruction given when learning a practice serves as guidelines to define on which side of the continuum a given practice falls. The use of this criteria will certainly evolve as we gain more knowldege on the meditative state neuronal and phenomenological correlates.

5.1.2 How to define meditation expertise ?

Assessing the meditation expertise of practitioners is another fundamental problematic that should not be overlooked. Recent studies have taken the length of meditative experience in hours and years as a criteria for meditation expertise as well as judgement from the meditation teacher or community on the qualities of the practitioners (Brefczynski-Lewis et al., 2007; Lutz et al., 2008a). Dayli practice, even for short periods of time seem to be also preferrable than occasional extensive practice.

5.2 The different types of meditation

Meditation traditions exist all over the world. An encyclopedia would be necessary to attempt to describe each and every one of them. Here I will focus on only a few of them, mostly meditation practices from Asian traditions, since these are the traditions that have been studied the most by Western scientists and the ones I studied in this PhD work.

Stage	Object	Subject	Reflexive Awareness
1	+	-	-
2	-	+	+
3	-	-	+
4	Ø	ø	++

-” = de-emphasis; “ ” = emphasis; “ø” = absent.

Figure 5.2: Schematic representation of the different stages in the practice of open monitoring meditation in the *Chag-zôg* Tibetan practice. This style of practice starts by developing concentration on an object (stage 1), before cultivating awareness of subjectivity in a manner that de-emphasizes the object. The practitioner then gains phenomenal access to reflexive awareness (stage 2). Subjectivity is then de-emphasized as well to enhance the acess to reflexivity (stage 3). Finally one moves to the point where the invariant aspect of awareness is fully realized in meditation. Taken from Lutz et al. (2007).

5.2.0.0.1 Soto Zen is a tradition based on mindfulness and open monitoring. One practices it while sitting, usually facing a wall with open eyes. Practitioners are instructed to observe their thoughts and emotions as they arise in their minds and not to cling to them or engage in narrative thinking but simply let these thoughts or emotions go and remain purely aware of sitting. Every time practitioners realize that the mind has started to wander (i.e., they identified with a thought), they have to bring their attention back to the present moment. This practice is also called Shikantaza, a Japanese term that means"nothing but precisely sitting." In Rinzai Zen, the other major form of Zen practice, practitioners are instructed to concentrate on koans. Koans are riddles that cannot be solved with knowledge or thinking."What is the sound of one hand clapping?" is a popular Zen koan. Zen students are given a koan by a Zen teacher, depending on their level of development in the practice and their personality. They are then instructed to meditate on it until they can solve it. They regularly present their solution to their teacher and, if successful, are given a new koan. Koans are ways to help meditators get out of the thought-based state of ordinary consciousness and access pure awareness of the present moment.

5.2.0.0.2 Vipassana meditation is another open monitoring meditation technique that is now widespread in the West. In Vipassana, practitioners begin by observing their breath around the area of the nostrils to help the mind develop sustained, focused attention. Every time the mind wanders, they have to bring it back to the sensation of breathing. As they do so, attention gets sharper and sharper. Then practitioners have to mentally scan sequentially and meticulously each part of the body and feel the sensation in each of these body parts . They continuously keep their attention moving down from head to toes and then up in the reverse direction. At first, they find it hard to experience sensation in each and every part of the body, but with practice, they progressively come to feel sensations in more parts of their bodies. Participants are only instructed to keep their attention moving and observe, objectively and with equanimity, the sensations that they are experiencing. Practitioners should try to avoid developing feelings of aversion or cravings for specific sensations, as this is believed to disturb both body and mind. Vipassana is a good example of a meditation practice in which focused attention and open monitoring are both incorporated.

5.2.0.0.3 Mantra or prayer meditation might be the most popular type of meditation worldwide and is present in Tibetan Buddhism, Sufism, Hinduism, and many other traditions. It is a type of concentrative meditation. Matra meditation became widespread in the West in the 1960s with the development of the Hare Krishna society. A mantra is a religious or mystical sound, word, or poem that can be either recited aloud or subvocally. For instance, Hare Krishna practitioners are instructed to repeat the 16-word Hare Krishna mantra,"Hare Krishna Hare Krishna, Krishna Krishna Hare Hare, Hare Rama Hare Rama, Rama Rama Hare Hare," 1,728 times a day, keeping the correct count with the help of prayer beads. The particular body vibration that a mantra induces is believed to calm and focus the mind and body without the need for intense concentrative efforts. When meditators repeat the mantra, they are instructed to focus their full attention on the recitation, and also sometimes on its meaning if it has one.

Mantra meditation is in many ways similar to slow reading or chanting of sacred texts while one absorbs their meaning. These practices are present in all religions and spiritual traditions. Texts involved may be sutras in Buddhism (discourse from the Buddha). Christian practices, for instance, involve recitation of a prayer phrase or the study of Scripture, which involves the slow reading of the Bible as the reader considers the meaning of each verse, and is practiced by monks of various orders. Although these practices are usually not specifically referred to as meditation, they involve focused attention and going beyond dialectic thinking, two traits they share with meditation.

5.2.0.0.4 Himalayan Yoga Tradition is an ancient tradition consisting of many steps and paths that are integrated with each other. For example: (1) deep relaxation techniques performed in ‘corpse position’, finally leading to yoga-nidra (the sleep of the Yogi). (2) correct position of spine in sitting for meditation, together with diaphragmatic breathing and number of other breathing exercises. (3) Breath awareness practices. (4) Mentaly repeat a sound or series of sound (mantra) and at the same time focus on their breathing and, in more advanced practitioners, specific body energy centers (chakras). In the Himalayan Yoga tradition, the mantra is made of Sanskrit syllables chosen by their meditation teacher and may or may not have a specific translation into regular language. The mantra may also be used only as a thought without breath awareness. The vibrations that a particular mantra induces are considered to calm and focus the mind and body without the need for intense effort of concentration. During the course of a meditation session, when a certain level of transcendance is felt, the practioner can let go of the mantra repetition.

5.2.0.0.5 Transcendental meditation pertains to the passive class of meditative practices. A mantra is given to the practitioner and he/she has to repeating it while seating with eyes closed and letting his/her mind drift and not concentrate on anything in particular (Morse et al., 1977). This technique is described as “easy, enjoyable and does not involve concentration, contemplation or any type of control” (Wallace, 1970). Transcendental meditation is among the most popular form of meditation among Westerners and has in fact be adapted for them based on Indian meditative traditions.

5.2.0.0.6 Isha Yoga Isha meditators practice a form of yoga called Isha Yoga, which includes Asanas (yoga postures), Kriyas (specific breathing techniques and body postures) and sitting meditation (Shoonya and Samyama meditations). The Isha Yoga practices are designed to purify, balance and enhance one’s energy system. During the Asanas and Kriyas, practitioners focus on the breath and body sensations; during the meditations, the practitioners maintain awareness of their thought process and – with the Samyama meditation – also their breath. When practicing Shoonya meditation the meditator goes through a process of conscious non-doing that creates a distance between one’s self and one’s body and mind. For the duration of the meditation, the practitioner consciously does not respond to any internal or external stimuli. Shoonya meditation can be realated to the passive meditation practices.

5.2.0.0.7 Other forms of meditation may involve generating and focusing on feelings of loving-kindness or compassion toward all living beings (one of many Tibetan Buddhism practices). Mental visualization and careful examination of sacred objects is another common mediation practice in Tibetan Buddhism. Different practices can also be done while one is moving. In the case of walking meditation, one has to walk slowly, keeping breath coordinated with each step, and remain aware of every body sensation and movement. While working or doing simple tasks, one may simply be present and focused on the action being done now, that is, giving the present moment one’s undivided attention, without thinking about past or future events. Walking and work meditation are an important part of Zen practice. Yoga is also a form of meditation in movement. It combines specific physical postures, breath patterns, and body awareness.

In most meditation traditions, daily practice is supplemented by retreats that involve intensive practice. These retreats are often held in complete silence. They can last from a few days to several months or even years. In the Tibetan meditation tradition, for instance, it is not uncommon to see dedicated practitioners engage in monastic life spending several years of their lives in complete silent isolation.

5.2.0.0.8 Clinically-derived meditation practices Meditation as mental training for regulation of attention finds clinical applications. Deficit of attention have been found in numerous mental disorder ADHD (Attention Deficit and Hyperactivity Disorder) (Pasini et al., 2007), unipolar and bipolar depression (Williams et al., 2000; Gruber et al., 2007; Jongen et al., 2007), anxiety disorder (Dupont et al., 2000; Shapiro and Lim, 1989) and schizophrenia (Liu et al., 2006; Luck et al., 2006). Since about twenty years, type of cognitive-behavioral therapy (CBT) developed that are integrating attention reeducation based on the practice of mindfulness, a way of paying attention to the present moment that can be acquired through meditation practice (Baer, 2003). These mindfulness-based therapies reveal helpful in the treatment of numerous mental disorders (Baer, 2003; Grossman et al., 2004; Hayes and Feldman, 2004; Ma and Teasdale, 2004; Teasdale et al., 2000). Mindfulness training is also offered in stress-reduction program (Kabat-Zinn, 1990).

In the next chapter we will review experimental work showing the effects of meditation practice at the brain and body levels. We will see that although there seems to be good evidences for an implication of meditation in cognitive and physiological changes, little is known on the actual mechanisms of action of meditation and that there are still important methodological flaws in meditation research. Chapter 7 will present our comparative study of EEG oscillatory activity in 3 different types of meditation.

Chapter 6

The effects of meditation on the body and brain

Contents

This chapter is inspired from a book chapter published in 2010, Braboszcz et al. (2010). Here, I present the state of the art scientific knowledge on the effects of meditation on the brain and body.

6.1 Meditation and the peripheral nervous system

Since meditation is often considered to be a relaxation technique, it is reasonable to assume that meditation practice affects the functioning of the body. The mechanisms underlying the effect of meditation on the body are not yet understood, and as for cognitive and brain activity correlates of meditation, we currently lack formal evaluation procedures for the diverse meditation types and methodologies being used (Cahn and Polich, 2006). Only a brief overview of interesting research directions is provided here.

6.1.1 Body Representation

Meditation induces long-lasting changes to one's body perception that can be observed both at low-level cortical representations and at higher-level representation associated with the sense of self (Cahn and Polich, 2006). Meditation-induced changes in cortical areas devoted to process inputs from the body are reported by Lazar et al. (2005) and could account for increased awareness of the sensory field. Lazar et al. (2005)'s study shows that regular practice of open-monitoring meditation—which focuses on both internal and external sensations—increases the thickness of the cortex in somatosensory areas of the brain. This increase in cortex thickness was positively correlated with meditation experience, so we may hypothesize that it functionally corresponds to an increase in body awareness. Testing this hypothesis, Khalsa et al. (2008) had long-term meditators in both active (yoga) and sitting forms of meditation and non-meditators perform a heartbeat detection task in which participants had to tell whether or not short sounds were displayed synchronously to their own heartbeats (they had to try to feel their heartbeats without using their finger on peripheral arteries). They found that the meditators did not perform any better than the non-meditators. This suggests that changes in meditators' body representation are not functionally correlated with better perception of physiological sensation. However, in this study, meditators systematically rated their experience of interoceptive perception higher than did control subjects. Collection of their subjective experiences also revealed that they found the heartbeat-counting task to be easier than non-meditators did. It is relevant to note that attention to the heart beat is generally not employed in meditative training. A different study by Farb et al. (2012) studied changes in interoceptive attention during a breath awareness task, which is the most basic practice usually given when starting to meditate. They found that attention to the breathing involved greater activation of interoceptive attention related part of the insula in a group of subjects after mindfulness-based stress reduction training compared to subjects from the waitlist (Farb et al., 2012). Lazar et al. (2005)'s results might then directly index improved body awareness without general improved of body representation. Following meditation training there would be better perception of only those sensations that are the object of specific attention during the practice of meditation. toward an "impersonal beingness" (Cahn and Polich, 2006).

6.1.2 Effect of Meditation on the Autonomic and Immune System

Meditation affects bodily functions in two different ways: standard daily meditation practice creates a low arousal state, and peak meditation experience fosters a high arousal state. According to early theoretical models, infrequent peak experiences have quite a different high arousal tone than the more common meditative states (Cahn and Polich, 2006), but it is difficult to study such experiences because of their rarity. This section will thus only review data concerning the usual trait commonly experienced during meditation practice. Based on early studies of transcendental meditation, Jevning et al. (1992) qualify the common meditation state as a "wakeful hypometabolic state".

The autonomic nervous system controls the activity of organs and viscera in the body. It is composed of the sympathetic and parasympathetic neural pathways. Although this is a schematic view and the reality is far more complex, these two components are usually believed to have opposite actions on their targeted organs or tissues. The sympathetic system is most often involved in energy mobilization, preparing the organism to react (flight-or-fight response, response to stress), whereas the parasympathetic component is responsible for most resting and restoration functions (rest and digestive functions) of the organism (Jänig, 2003).

One possible way for meditation to act on autonomic activity is through respiration control. Respiration is one of the body's few autonomic functions that can be controlled and can affect functioning of the autonomic nervous system (Badra et al., 2001; Eckberg et al., 1985). Many meditation traditions consider breath, body, and mind to be linked and thus have given, whether explicitly or not, the breath a central role in meditation practice. Voluntary control of the breath may be achieved through specific inhalation-exhalation rhythmic patterns, as in pranayamic practice and the slow diaphragmatic breathing practiced in yoga that involves specific movement of the thoracic cage. Breath also tends to involuntarily slow down during mantra chanting (Bernardi et al., 2001), breath-counting meditation, and simple awareness of the breath (Lehrer et al., 1999).

Slower respiration rate during meditation practice induces changes in cardiovascular activity that correspond to an increase in the activity of the restorative parasympathetic system (Saul, 1990). This increased parasympathetic activity has also been assessed through the slowing down of basal heart rate in meditators (Pal et al., 2004) and the increased synchronization, or respiratory sinus arrhythmia (RSA), between the breathing cycle and the heartbeat during meditation (Cysarz and Bussing, 2005; Ditto et al., 2006). RSA corresponds to high variability in heart rate as heart rate becomes faster during inhalation and slower during exhalation. Mechanisms behind human RSA are not yet well understood (Grossman and Taylor, 2007; Tzeng et al., 2009) but might be important to meditation research, as RSA could be used as an index of successful emotion exposure during meditation (see 6.3). Slow breathing has also been associated with increased baroreflex sensitivity (Joseph et al., 2005; Reyes del Paso et al., 2006). Decreased blood pressure is often reported after meditation practice by both healthy individuals and hypertension patients (Carlson et al., 2007; Manikonda et al., 2008). Improved control of blood pressure is usually considered a sign of balance between parasympathetic and sympathetic activity. Finally, since one role of sleep is to restore the balance in these autonomic systems, the fact that meditators typically require less sleep than control subjects (Ajaya, 1976) suggests a better balance between these two systems.

Although few studies have been conducted, there is increasing evidence that meditative practice also affects the immune system. Psychological states such as stress affect the functioning of the immune system (Segerstrom and Miller, 2004). The immune system is indirectly under the influence of the central nervous system via hormonal signaling and through activity of the autonomic nervous system (Dantzer and Kelley, 1989; Jänig, 2003). Davidson et al. (2003) found faster peak rise for the antibody response to a flu shot among healthy meditators who underwent an 8-week mindfulness-based stress reduction (MBSR) training course in open-monitoring meditation than among non-meditators. Increased number and increased activity of lymphocyte T and other natural killer cells have also been found in HIV patients after MBSR training (Robinson et al., 2003; Taylor, 1995).

Finally, in a recent study, Pace et al. (2009) assessed the effect of compassion meditation (in which one works at developing altruistic emotions and behaviors towards all living beings) on the immune response and found a negative correlation between the amount of meditation practice and induced stress immune response.

We should develop a better understanding of meditation effects on the autonomic and immune systems as we improve our understanding of these systems' relationship and their dynamic links to the central nervous system. Study of slow oscillatory activity in both the central and autonomic systems would likely shed light on coupling mechanisms between the brain, vegetative functions, and the mind (Basar, 2008).

Jerath et al. (2006) built a model of synchronization between the cardiopulmonary and the central nervous systems to explain how slow, deep pranayamic breathing practiced in yogic meditation can influence the autonomic nervous system. Davidson et al. (2003) also found that left-sided anterior oscillatory activity of the brain is positively correlated with activity of the immune system after meditation practice, assessing through the quantity of natural killer cells. This type of hemispheric activity has also been correlated with both the autonomic system activity and emotional regulation (Craig, 2005), as we will see in the section dealing with emotions.

Thus, although a growing body of evidence showing a link between mind and body states has accumulated over the years, more research will be needed to unravel the mechanisms underlying the effects of meditation on the autonomic and immune systems.

6.1.3 Meditation and Aging

As we have seen, meditation training seems to protect against stress and boost the immune system. It has also recently been shown to reduce neuronal decay due to normal aging. Pagnoni and Cekic (2007) found greater prefrontal cortex thickness in middle-aged meditators than in non-meditators, as well as a decline in cortical thickness associated with age, a result that is also reported by Lazar et al. (2005). Nagendra et al. (2008) also showed that expert Vipassana meditators did not present sleep patterns associated with aging. Both the length of the slow waves sleep period before the occurrence of the first rapid eye movement (REM) sleep episode and the total length of REM episodes typically decrease with age. Nagendra et al. (2008)'s study showed that this decrease was drastically smaller in meditators of age 50–60 than in control subjects of the same age. This suggests that meditation slows down the brain-aging process through a mechanism that has yet to be discovered.

6.2 Meditation and attention

The cognitive function that meditation may affect the most is attention, since meditation is a form of attention training. Meditation is a skill and as such it may train attentional systems. As physical training strengthen body muscles, mental training involved in meditation reinforces brain attentional circuits. Meditation recruits attentional brain areas involved in learning.

Using fMRI, a technique that monitors metabolic activity in the brain as reflected by variations in blood flow, Brefczynski-Lewis et al. (2007) found that in a group of

Tibetan Buddhist meditators, focused attention meditation is associated with greater activation in multiple attention-related brain regions (dorsolateral prefrontal cortex, superior frontal sulcus, and intraparietal sulcus). Interestingly, brain activation varied based on the person's level of expertise. Expert meditators had less activity in attention-related brain regions, whereas greater activity among less expert meditators was associated with skill acquisition. This reduced metabolic activity in attention-related regions of highly expert practitioners suggests an effortless — though efficient — strategy for attentional resources allocation. This is supported by traditional Buddhist descriptions of a decreased need for voluntary attentional effort to attain concentration for expert practitioners.

Using electroencephalography, Lutz et al. (2004) also found that brain activity varies based on expertise. These results suggest that meditation is a technique that is learned and perfected over years of practice.

According to Lutz et al. (2008a), meditation practices involve at least three attention regulation subsystems. First, meditation may involve intense object-based concentration. Selective attention—or orienting—is the selection of specific information from the flow of sensory input and involves cortical structures known to gate information, such as the temporal-parietal junction, the ventrolateral prefrontal cortex, the frontal eye field, and the intraparietal sulcus (Corbetta and Shulman, 2002). Second, meditation imposes continuous monitoring of the focus of attention. Sustained attention—or alertness—is the maintenance of a state of high sensitivity to a perceived stimulus or mental object over time and most likely involves sustained synchronous activity between the thalamus and the right frontal and right parietal cortical structures—also known as the thalamo-cortical loop (Berger et al., 2007; Coull, 1998; Posner and Rothbart, 2007).

Finally, meditation also involves transient attention shifts, as when one disengages attention from a source of distraction and redirects it to the intended object of concentration (Cahn and Polich, 2006; Lutz et al., 2008b). This involves executive attention — or conflict monitoring — which is the monitoring and resolution of conflicts among thoughts, feelings, and mental plan. Increase of executive attention capacities following meditation training is supported by behavioral data of meditators performing the Stroop task. The Stroop task requieres indicating the ink color of stimuli made of color names that could be written in a matching or mismatching ink color. When presented a color name written in a mismatching ink color, naming the ink color requieres executive attention capacities to overcome the automatic processing of the linguistic material. Performing the Stroop task meditators are faster and make less errors than control subjects (Moore and Malinowski, 2009; Wenk-Sormaz, 2005). Executive attention is managed by the dorsal anterior cingulate cortex and the dorsolateral prefrontal cortex, structures that have also been shown to be activated when one is self-conscious (Ridderinkhof et al., 2004; Weissman et al., 2006).

6.2.1 Meditation Improves Perceptual Attention Capacity

Perceptual pre-attentive processes are sometimes under voluntary control—as, for instance, when we focus our attention on an object or sound—although they may also be affected by environmental cues. Selective visual attention focused on an object may be involuntarily influenced by the surrounding objects; for example, distracting visual stimuli of high contrast have been shown to automatically redirect this type of attention (Friedman-Hill et al., 2003). Below, we show how meditation affects involuntary allocation of low-level attentional resources.

In the auditory domain, pre-attentive processes involve the automatic detection of environmental changes and can be studied in the laboratory through the brain's electrical response (event-related potential) to a flow of frequent auditory stimuli interspaced with infrequent ones. The amplitude of the differential electrical activity between frequent and infrequent stimuli, called mismatch negativity, was found to increase immediately among expert practitioners after a focused attention meditation session (Srinivasan and Baijal, 2007).

Similar findings were found for Vipassana meditation (Cahn, 2007). Focused attention training and the higher degree of awareness of the body and sensations induced by meditation might be responsible for increased sensory cortex sensibility. According to one interpretation, neuronal populations tuned to different stimuli inhibit each other and compete for attentional resources (Näätänen, 1992). Neuronal populations tuned to properties of the standard stimulation respond less vigorously upon repeated stimulation and become desensitized. Thus when a deviant activates a distinct new neuronal population, these fresh afferents respond more vigorously, eliciting mismatch negativity. Meditation would make these perceptual systems sharper and more sensitive.

Experimental work also shows that open-monitoring meditation increases processing capacity in the visual system. This evidence comes from a study using the attentional blink paradigm. In this paradigm, two stimuli are presented in close succession. As a result of allocation of all attention resources to the first stimulus, the second one is often not perceived. However, both behavioral and event-related potential results show that intensive 3-month open-monitoring retreats decrease the attentional engagement in processing the first target, thus allowing subjects to process and perceive the second one (Slagter et al., 2007).

These results indicate that meditation tends to boost low-level attention. This could be due to increased attentional resources. Meditation could recruit new attention-dedicated neuronal networks or strengthen existing ones. Another hypothesis is that attentional resources are constant. However, since meditation tends to quiet the mind, we may observe a disengagement of attention from higher cognitive and verbal areas. If attentional systems are not dealing with thought affects, they might have more resources to deal with low-level perceptual systems.

6.2.2 Meditation Decreases Perceptual Habituation

Neural and perceptual systems tend to habituate to repetitive presentation of stimuli, to which early responses are larger than later ones. Meditation has been shown to decrease perceptual habituation to repetitive stimuli. This type of effect has been mostly observed in open-monitoring meditation, in which the practitioner develops attention to the present moment-to-moment experience without allowing his or her attention to wander. In this meditation, each stimulus is seen as fresh and new in the present moment. As an individual practicing open monitoring works on perceiving each experience as it arises in the moment without judging, it might cut off automatic brain mechanisms responsible for habituation, establishment of routines, and action scenarios. A classical habituation paradigm involves repetitively presenting the same stimulus and observing the decrease in the induced 10-Hz brain alpha wave amplitude with the number of stimulus presentations. Non-habituation was demonstrated with open-monitoring meditators where the electroencephalographic alpha rhythm amplitude did not decrease after repeated stimulus presentations (Deikman, 1966; Wenger and Bagchi, 1961). These findings are also consistent with Cahn and Polich (2009) study showing less automated recruitment of frontal attentional circuits when rare and salient auditory stimuli are processed during Vipassana open-monitoring meditation practice.

Open-monitoring meditation also allows for faster reallocation of attentional resources. Valentine and Sweet (1999) used an auditory sustained attention task in which participants had to mentally count the number of beeps in several series of tones presented at different rates. In general, fast series came unexpectedly. Open-monitoring meditation resulted in better counting performance in the unexpected fast series. Interestingly, this effect was not observed with focused attention meditation. One explanation is that practitioners of concentrative meditation might have focused intensively on the slow series and may have difficulty shifting their attention to start counting the faster series. On the other hand, open-monitoring practitioners, who only partially practice engaging their attention, could more easily shift their attention to the fast presentation rate. These results indicate that meditation allows for non-habituation and faster reallocation of attention. Beyond low-level attention allocation, we will see now that meditation also has unexpected effects on the activity in higher perceptual areas.

6.2.3 Meditation Reduces Neural Population Competition in Higher Perceptual Areas

Carter et al. (2005) reported results of a study of 23 Tibetan Buddhist monks who have been engaged in either focused attention or open-monitoring meditation. These monks were asked to perform a"binocular rivalry" task during which they were presented with two images, one before each eye. Under these circumstances, they were randomly experiencing either both images simultaneously or each of them alternatively for 2–3 seconds as the images competed for attentional resources in the visual system. No effects of open-monitoring meditation were observed either during or after the practice. However, monks practicing focused attention meditation were able to maintain a stable, superimposed percept of the two competing images for a longer than normal duration. These results suggest that selective and sustained attention allows conflicting stimuli to be perceived simultaneously by long-term expert practitioners both during and following focused attention meditation. This also points to the remarkable influence of meditation training on the brain, as no other mental training has been shown to affect allocation of attentional resources responsible for binocular rivalry.

Open-monitoring meditation also seems to allow meditators to more efficiently process stimuli competing for attentional resources. The Attention Network Test has been used to assess open-monitoring meditation influence on attentional subsystems. The test has subjects indicate the direction of a target arrow surrounded by flanker stimuli that either point in the same or reverse direction, thus inducing perceptual conflict (Fan et al., 2002). Results show that after 5 days of open-monitoring meditation training, participants improved their performance in responding to trials with conflicting conditions (Tang et al., 2007). Both of these experiments show that meditation helps to efficiently process different conflicting stimuli.

6.2.4 Meditation and Higher-Level Attention for Monitoring Mind Wandering

While meditation practice benefits psychological well-being, mental states with a high frequency of mind-wandering episodes, such as depression or boredom, are experienced negatively. Carriere et al. (2007) found that frequent brief lapses of attention, that is, lack of conscious awareness of one's action, is associated with proneness to boredom and depression among students. More frequent and intense periods of mind wandering during a word-encoding task have also been linked to dysphoria (Smallwood et al., 2008). On the other hand, an open-monitoring meditation offered to students during a month of MBSR intervention reduced their psychological distress as well as their ruminative thoughts (Jain et al., 2007).

In favor of this hypothesis, Farb et al. (2007) revealed distinct fMRI neural activation patterns in control subjects with no meditation training compared to subjects who followed an 8-week open-monitoring MBSR program. Control subjects were primarily experiencing a mental narrative state, where one allows one's attention to be caught by a given train of thought, whereas meditation practitioners were aiming at experiencing moment-to-moment awareness of the self. Mental narrative led to strong activation of the mPFC, and awareness of present experiences led to decreased activation of the mPFC and increased activity in right lateral PFC and right viscero-somatic areas (Farb et al., 2007). Thus there might be two possible types of experience of the self: one—engaged during mind wandering—based on thoughts dealing with past or future experiences of the ego, and one based on the moment-to-moment experience of the self, involving awareness of sensory information from the body. This indicates that the experience of self in the present moment is dramatically different both experientially and in terms of brain activity from the experience of self as projected in the past or the future, as in mind wandering. This hypothesis is further supported by the findings that during the practice of meditation, experienced meditators show less activity of the default mode network than novice meditators, indicating alteration of the brain functionning that is consistent with the decrease of mind wandering in expert meditators (Brewer et al., 2011).

6.3 Meditation and emotion

Regardless of the specific meditation technique, meditation leads to state and trait experiences involving a deep sense of peace and calm. In fact, achieving enduring happiness by freeing oneself from affliction is the central doctrine of Buddhism (Ekman et al., 2005). The fact that meditation affects the way emotions are experienced and allows for better regulation of negative and distressing feelings is in part an outcome of meditation-induced changes on body, brain, and cognitive functioning. On a side note it is interesting to remark that Buddhism, from which originated most Asian meditation practices, have evolved in cultures of Pali, Sanskrit and Tibetan languages, which do not have a specific word for "emotion" (Ekman et al., 2005).

Emotions may be seen as a set of interrelated changes in the body in response to a real or imagined situation or stimulus. Emotions are experienced as feelings and may interrupt ongoing behavior or mental processes in the form of an urge to engage in action (e.g., flight for fear, outburst of anger), depending on the emotion felt (Hamm et al., 2003). Emotions elicit responses and changes both in the body and in the attentional systems. Increased processing of body sensory inputs might also affect the way emotions are first perceived through somatosensory information. Increased concentration results most likely in better control of mind wandering; that is, enhanced attention and better resistance to distraction might reduce emotional reaction by reducing negative emotions' propensity to interrupt the ongoing stream of thoughts and behavior. Changes in attentional capacities are also most likely linked to changes in brain activity, especially in the anterior areas, in which neural activity has been linked to the functioning of the autonomic and immune systems, which are known to be affected by meditation.

6.3.1 The Links Between Brain, Body, and Emotion

In the last 20 years, asymmetries in brain electrical activation have been linked with the way people react to emotional situations and regulate their emotions (Allen and Kline, 2004; Wheeler et al., 1993). In individuals who tend to react positively and let go quickly of negative emotions, the baseline electrical activity of the brain exhibits greater left-sided anterior activation than recordings of individuals who are more prone to nourishing negative emotions (for a review see Davidson, 2004). After 6 months' practice of mindfulness and MBSR meditation, healthy participants showed enhanced left-sided prefrontal electrical activity in the alpha band after induction of both positive and negative feelings (Davidson et al., 2003). The same study found increased left-sided PFC activity to be associated with reduced anxiety and negative affect as well as increased experiences of positive affect. These results correlate with previous ones demonstrating that people with more left-sided baseline activation in the PFC have a more positive outlook on life than individuals with right-sided PFC activation (Davidson, 2000).

The relationship between positive affect and anterior brain areas activity is strongly supported, as reviewed by Craig (2005), by the anatomical connectivity between the autonomic system and anterior brain areas. Craig demonstrates clearly how the left anterior part of the brain interacts more directly with the parasympathetic system and the right anterior part interacts more directly with the sympathetic system. Activity in either of the hemispheres is thus associated with behavior and emotions in accordance with the opposite actions of these two components of the autonomous nervous system. Thus left-sided activation would correspond to more enriching emotions, that is, those eliciting positive, group-oriented behaviors, whereas right-sided activity would imply activity of the sympathetic system and thus reactions associated with negative, aversive behaviors.

6.3.2 Meditation and the Regulation of Emotions

During most meditation practice, practitioners are encouraged to keep a balanced, nonjudgmental state of mind. Practitioners can achieved this by experiencing feelings arising in their mind, then stay for a period of time, and later pass away. While meditating, practitioners in most meditation traditions are instructed to keep a calm, balanced mind, noticing affects with no feeling of aversion toward unpleasant emotions or feelings of desire for pleasant, enjoyable ones.

Contemporary research on emotion outlines two means through which emotion regulation may be achieved: attentional control and cognitive control (Ochsner and Gross, 2005). Attentional control involves manipulating the amount of attention that is naturally allocated to process emotional stimuli. Exercising cognitive control involves changing expectations or judgments about emotional stimuli. Both of these strategies are supposedly present in meditation, whether attention is focused away from the emotion (such as in concentrative practices) or the emotion is simply being observed (such as in contemplative mindfulness practices). Cognitive control is also achieved indirectly: as meditators gain insight into their minds and bodies, their appraisal of emotion automatically evolves. In addition, meditation may also change emotion's appraisal by changing the practitioner's beliefs about the world.

The way meditation modulates pain perception may provide a good overview of how meditation affects the process through which emotions give rise to specific feeling. Pain is defined as an"unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (IASP, 1994). Recently, pain has been described in terms of a homeostatic emotion, that is, as a feeling from the body (like thirst or hunger) that elicits a specific behavior to preserve body equilibrium (Craig, 2003).

Numbness and pain that arise from long periods of sitting without moving is a common side effect of meditation practice during retreats. Constantly changing position whenever pain arises would disturb meditation, so meditators are asked to use different strategies to cope with pain. According to Gunaratana (2001), it is best to adopt a voluntary and focused attitude of simply watching the pain—that is, experiencing the pain without identifying with it. Practitioners may also try to lessen the importance of the pain by comparing it with the pain that one experienced previously in one's own life, or pain that others are experiencing. Another strategy would be to divert the attention toward another object, such as the breath, and as a last resort to slowly stretch the muscles to see if the pain can be lessened. It is said that with practice, it takes more time for pain to arise and that it becomes less intense. This resistance to pain, which is a major component of meditation retreats, probably helps meditation practitioners cope with their own suffering in a more detached way after the retreat is over.

Treatments of chronic pain based on diverse meditation practices, such as MBSR programs (Kabat-Zinn et al., 1985; Morone et al., 2008) and loving-kindness meditation (Carson et al., 2005), have revealed positive outcomes associated with improvement of overall quality of life. Enhanced tolerance of acute pain has also been assessed in different studies with both focused attention and open-monitoring meditation. Longitudinal study of transcendental meditation (TM) shows decreased brain activation in the thalamus, prefrontal cortex, and anterior cingulated cortex in response to acute pain (immersion of the hand in hot water) after 5 months of TM daily practice in participants who were new to meditation (Orme-Johnson et al., 2006). This study further suggests that TM practice does not change actual pain sensations (as pain rating didn't change pre– or post–TM practice and never significantly differed between beginners and long-term practitioners) but does reduce emotional distress associated with pain, resulting in enhanced tolerance of acute pain. Results of this last study are of particular significance, as they highlight meditation's effects on the regulation of the distress associated with painful feelings. Thus meditation practice changed the way individuals reacted to the emotion related to pain. In fact, meditation seems to be acting at the feeling level, in the way pain sensations are experienced subjectively as emotions. One hypothesis is that meditation training that involves developing a nonjudgmental attitude leads to change in emotion representation, resulting in less body and mental disturbance.

In fact, the different forms of self-consciousness experienced during meditation (Farb et al., 2007) and the emphasis placed on equanimity and body sensations suggest that meditation leads to a different appraisal of somatic markers than the common normal state. According to the somatic marker hypothesis of Damasio (1994), emotions mark our experiences in terms of body representation, and these somatic markers are then used to evaluate new situations and experiences. Feelings are based on bodily response and precede emotions, which are viewed as mental reactions to feelings. In this framework, keeping a nonjudgmental state of mind during meditation could delay or attenuate emotional reactions to feelings.

6.3.3 Meditation, Emotion and Brain Imaging

The regulation of emotions, especially of negative ones, has been extensively studied using brain-imaging techniques. Studies show that meditation actually affects at least three important areas of the brain emotion circuitry: the amygdala, the PFC and the . The amygdala is engaged in producing autonomic, endocrine, and somatic responses as well as directing attention toward affective stimuli that are potentially important, such as potential threats or potential sources of food (Davis and Whalen, 2001). The PFC down-regulates neural activity in the amygdala and the two areas share reciprocal connections (Banks et al., 2007; Davidson, 2002) and the anterior cingulate cortex (ACC) is involved in the self-regulation of emotion and behavior (Rothbart et al., 2011).

In the past few years successive studies have shown that a few days of a mindfulness-based traditional chinese meditation increases the activity of the ventral part of the ACC (Tang and Posner, 2009) and that after 11 hours of practice over 4 weeks, the white matter connectivity of the ACC improved through increase myelinisation (Tang et al., 2010, 2012). In addition, Less body arousal and EEG brain activation has been observed in response to negative affects for yoga practitioners (Aftanas and Golosheykin, 2005). Consistent with this, when one is engaged in focused attention meditation, fMRI studies show that amygdala activity in response to emotional negative or positive sounds is decreased in long-term Tibetan expert practitioners compared to novice ones. Interestingly, the more hours participants have spent meditating in their lifetimes, the more important is the decrease in amygdala activity (Brefczynski-Lewis et al., 2007). However, fMRI studies show that when engaged in focused compassion meditation, expert meditators from the same tradition exhibited greater amygdala activation in response to emotional stimuli than novice practitioners (Lutz et al., 2008a).

These seemingly opposite results suggest that meditation allows for a wider range of emotional experiences, and that these experiences can be modulated through the practice of specific meditation techniques. Greater embodiment or disembodiment of emotions can be achieved through voluntarily modulation of dedicated attentional circuits that have been intensively trained through meditation practice. Consistent with this hypothesis, subjective reports indicate that meditation seems at first to intensify the experience of positive as well as negative feelings. Then through practice, these intense feelings are accepted and might contribute to the experience of a richer internal life, as reported by meditation practitioners.

Taken together, brain-imaging results support the empirical hypothesis of meditation-induced emotion regulation and suggest that it involves brain plasticity. The regular practice of meditation affects the connections between the emotional limbic system and the neocortex in such a way that it would change the individual's thoughts about and interpretation of negative emotions (i.e., his appraisal of his emotion).

6.4 Challenges in meditation research

In this chapter we have seen that meditation affects the physiological, neuronal and cognitive levels. Given the large diversity of meditation practices, it may be asked wether all types of meditation lead to the same effects. However, studies directly comparing groups of meditation practitioners from different traditions are scarce, although the existing few indicate different outcomes from different meditation practice (see Carter et al., 2005; Valentine and Sweet, 1999). In addition, there are still important methodological flaws in a lot of studies of meditation. A report from the United States National Center for Complementary and Alternative Medicine dated from June 2007 examined 813 studies published since September 2005 stated:

> Scientific research on meditation practices does not appear to have a common theoretical perspective and is characterized by poor methodological quality. Firm conclusions on the effects of meditation practices in healthcare cannot be drawn based on the available evidence. Future research on meditation practices must be more rigorous in the design and execution of studies and in the analysis and reporting of results. (Ospina et al., 2007, pg.6)

In the next chapter, in an attempt to fill some of the methodological and experimental gaps presented here, I present an experiment comparing the brain EEG activity of 3 groups of meditators practicing 3 different meditation traditions and a control group.

Chapter 7

Comparative study of the EEG correlates of meditation

Contents

This chapter presents a study that we have conducted in Rishikesh, North-East of India, between the winter 2009 and the spring 2011. Our host laboratory, the Meditation Research Institute (MRI), is part of the Swami Rama Sadhaka Grama ashram, a meditation school held by Swami Veda Bharati that aims at teaching the Himalayan Yoga meditation tradition. The MRI acquired a Biosemi Active Two EEG system in 2007 and then contacted Arnaud Delorme, my PhD supervisor, and offered him to use it to conduct scientific studies on meditation. This was made possible by the BIAL foundation which awarded A. Delorme a small grant for a comparative study of meditation practices. This was in the summer before the start of my PhD. Between February 2009 and February 2010 I spent 7 months at the MRI recording two of the four groups of subjects for the experiment. The other 2 groups have been recorded in the winter and spring 2011 by Jonathan Levy and Manuel Fernandez. This study required to develop contacts with 3 meditation traditions in India, to recruit and organize the recordings of the subjects in our Rishikesh laboratory. Swami Veda was helpful for recruiting Himalayan Yoga meditators, Bhavani Balakrishnan was helpful for the recruitment of Isha Yoga meditators and Swami Aman, ajay Khatri, Mr. Sharma and Dr. Ravindra Pattanashetti were helpful for their help recruiting the Vipassana meditators. In addition contacts had to be made with the local population not practicing meditation to recruit control participants. I want here to acknowledge the help of laboratory assistants Mina Bhatt, Pooja Badoni, Stéphanie Pornin and Vinthia Wirantana for recording the subjects and recruiting control participants.

7.1 Context of the study

Electroencephalography is one of the major neuroimaging tools used to study meditation. One reason is the ease of use of EEG and relative low cost of such systems compared to other brain imaging modality. In addition, historically, EEG has been the principal neuroimaging technique available in the year 1960s when scientific studies of meditation started. Since then meditation has been shown to affect many EEG frequency bands Fell et al. (2010) with lasting trait changes Aftanas and Golocheikine (2001); Khare and Nigam (2000); Travis and Wallace (1999). However, as outlined in the much detailed review of Cahn and Polich (2006), it is very difficult to get a clear picture of the effects of meditation practice on the EEG, since these effects may vary from one study to the other and thus does not seem to be reliable.

What is the source of this variability ? It is not yet clear wether it originates from individual differences in the practice of meditation itself or if it is due to differences in the experimental set up and recordings.

Travis and Shear (2010) made an attempt to organize EEG results from existing studies of meditation within each of the three categories described above, focused attention, open monitoring and "automatic self transcendence", which corresponds to passive meditation - based on current knowledge on cognitive states associated with each frequency band. They suggested that focused attention might be associated with gamma and beta EEG frequency activity, while open monitoring more associated with theta power, and passive meditation with alpha coherence. Although Travis and Shear (2010) tried to include studies that were comparable in terms of subject's meditation expertise and experimental control, it is still questionable whether the reported EEG findings they summarize are specific to the meditation practices or are more influenced by differences in the protocols or in the population of the various studies assayed, and only studies using the same protocols and recording conditions across different meditative groups can resolve this question satisfactorily.

This chapter presents an attempt to clarify the EEG correlates of meditation by recording within the same experimental setting and using the same recording material 3 groups of meditators from different meditation traditions and a meditation-naive control group. In this chapter I address the hypothesis that different types of meditation lead to different neural correlates. The goal of this report is to compare 3 types of meditations, a focused meditation on mantra repetition, breath and body parts (Himalayan tradition), an open monitoring meditation based on body sensations (Vipassana) and a passive meditation (Isha Yoga). In addition, we are including a control group of meditation-naive participants. In an attempt to go past the shortcomings of earliest studies, we designed a study in which meditators from different traditions and meditation-naive control subjects are going through the same study protocol. We intend to compare and contrast brain activity from these different traditions.

7.2 The choice of a control mental state

Meditation practice requires to disengage from the processing of the spontaneous thoughts that are considered as naturally produced by the brain in a resting state (Christoff et al., 2009; Raichle et al., 2001; Killingsworth and Gilbert, 2010). An ideal control state would be to let our participants engage into mind wandering while resting , since according to our previous study, neural correlates of mind wandering are quite distinctive from those of a meditative activity (see 3).

In fact, the resting state is a control condition often used in the meditation litterature (for example Travis and Wallace, 1999; Khare and Nigam, 2000; Arambula et al., 2001; Aftanas and Golocheikine, 2001; Lutz et al., 2004). However, experienced meditators also often report spontaneously engaging into meditation when sitting with no specific task to execute. In addition, mind wandering can contains thoughts about both past and future events, a distinction that could affect the EEG activity.

To optimize our chances to obtain a mental state contrasting from the meditative state and that would be similar for all subjects, we chose an instructed mind wandering task (Cahn et al., 2010; Cahn and Polich, 2009) requiring subjects to keep on generating and paying attention to non-emotional memories. In addition, this control task can be executed in similar conditions (sitting with the eyes closed) as meditation.

The recording protocol consisted in two main blocks: one in which subjects engaged into meditation practice and the other in which subjects were instructed to let their mind freely wander through autobiographical neutral memories.

7.3 Methods

7.3.1 Participants

Recordings took place at the Meditation Research Institute (MRI) in Rishikesh, India. Subjects coming from the neighborhood of the institute received about 10 US dollars (500 Rupees) as a compensation and subjects that had to travel from different parts of India received about 20 US dollars (1000 Rupees) in addition to coverage of their travel fees, stay and meals in Rishikesh. Participants all provided written consent to participate in the study. The project was approved by the local MRI Indian ethical committee and the ethical committee of the University of California San Diego (IRB project # 090731).

Our participants were from 3 different meditation traditions: Vipassana (VIP), Himalayan Yoga (HT) and Isha Yoga (ISY). We gave detailed description of these meditation practices in section 5.2.

7.3.1.1 Vipassana participants

The Vipassana meditation technique practiced by all our Vipassana participants was the one taught by SN. Goenka [1] and in the following Vipassana meditation will refer to this technique. We recorded 20 Vipassana meditators and used data from 16 of these meditators. Meditators were chosen for inclusion in the study based on age, gender and years of practice of Vipassana meditation compared to meditators from other traditions and control subjects.

[1] http://www.vridhamma.org/VRI-Introduction

7.3.1.2 Himalayan Yoga participants

For the purpose of the experiment, Himalayan meditators were instructed to go though the relaxation stage while sitting and then repeat mentally their Mantra with or without the awareness of breath, and in case they felt they attained some level of transcendence, to let go of the repetition of the mantra. We recorded 27 meditators in the Himalayan tradition and used data from 16 of these meditators. Meditators were chosen for inclusion in this study based on age, gender and years of experience in the practice of the Himalayan meditation tradition.

7.3.1.3 Isha Yoga participants

For the purpose of the experiment, Isha meditators practiced only the passive silent meditation called Shoonya meditation. We recorded 20 meditators in the Isha tradition and used data from 16 of these meditators. Meditators were chosen for inclusion in this study based on age and gender and years of experience in the practice of Isha meditation.

7.3.1.4 Control participants

Control subjects did not have a meditation practice. However some of the subjects were used to chant prayers as part as their religious rituals. During the MED condition, control subjects were instructed to keep paying attention to their breath for the whole duration of the recording period. The exact instruction given to them was "keep paying attention to the sensation breath, of the inhale and the exhale. If you start mind wandering, come back to your breath". They were allowed to ask questions about the practice. We recorded 32 control subjects and used data from 16 of these subjects. Control subjects were chosen for inclusion in this study based on age and gender.

7.3.2 Tasks description

Participants sat either on a blanket on the floor or on a chair. Participants were asked to keep their eyes closed and the room was kept dark during the recording. An intercom allowed communication between the experimental and the recording room. Participants performed two blocks of 20 minutes, one of 'Meditation' (MED) and the other one of 'Instructed Mind Wandering' (IMW). In the MED block, participants were first instructed to pay attention to their breathing (MED1): they were told to focus on noticing the air flow in and out their nose, or if this was too difficult for them to notice how their abdomen moves along with their breathing rate. After 10 minutes participants were told through the intercom to perform to their regular meditation practice for the remaining 10 minutes (MED2; see below). In the IMW blocks, participants were instructed to remember autobiographical events from childhood to the most recent past. They were given a list of potential events to remember before the recording session as examples (the list involved birthdays, daily childhood life, travels, etc...). They were explicitly told not to think of a strongly emotionally charged event. To keep the IMW condition as close to the MED condition, after the first 10 minutes (IMW1) participants were told through the intercom to keep on doing the thinking task for the next 10 minutes (IMW2).

In addition, after each period of IMW and MED recording of spontaneous EEG activity participants were performing the following psychophysic tasks which results we will not report here: listening passively to an auditory oddball protocol, passively watching a steady-state visual evoked potential (SSVEP) protocol and watching emotionnaly charged images from the IAPS database, while performing an emotional categorization task. In addition, at the end of the last block participants where listening again to the oddball protocol but in an active way this time as they had to count and report the number of oddball higher pitch tones.

Immediately after each blocks participants completed a questionnaire and were allowed to stand up, stretch and walk. The questionnaire was made of 11 general questions about the quality of the meditation to be answered on a scale from 0 to 10 and 16 items from the subscales "concentration and awareness", "hindrance" and "relaxation" of the Meditation Depth Questionnaire (MEDEQ, Piron (2001)). Order of the blocks were counterbalanced between participants to prevent from an eventual order effect. The day preceding the study, participants were invited to visit the experimental room and to practice the tasks for 10 minutes (5 minutes IMW and 5 minutes MED). Participants entering the study as meditators were asked not to meditate before coming to the laboratory on the day of the experiment. Figure 7.3.2 describe the protocole timeline.

Groups constitution : Groups of subjects were matched based on gender and age, although perfect matching could not be achieved. Following this matching procedure we could constitute 4 groups of 16 subjects each. Because the ISY and VIP groups did not contain as many subjects as the CTR and HT groups, the matching process implied leaving out of the present analysis a large number of CTR and HT participants. The control and the Vipassana groups contained 5 females, and the remaining groups 2.

In each groups, 8 of the subjects performed the mind-wandering task first and 8 subjects performed the meditation task first. Table 7.1 indicates the statistics for the different traditions. A year of meditation indicates a daily practice of at least 20 min-

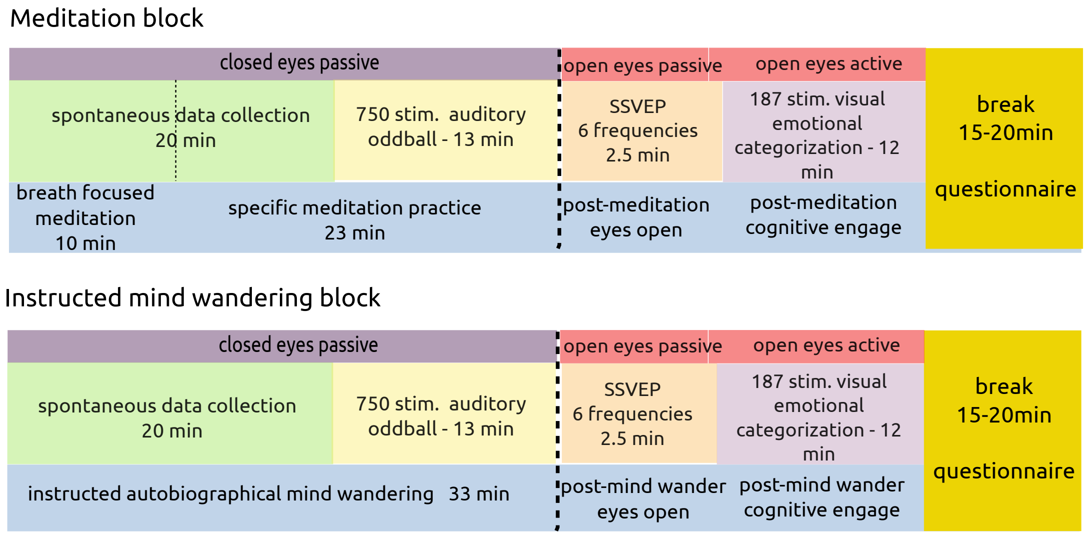


Figure 7.1: Protocole timeline of the EEG comparative study of meditation. The meditation block started with 20 minutes of closed-eyes meditation with the 10 first minute being a breath focused meditation and the 10 last minutes being the practice specific to each groups while control subjects kept on doing the breath focused practice. After the end of the 10 minutes, an auditory oddball protocol was played, and subjects had to keep on doing their meditation practice. During all this period subjects were instructed no to pay attention to the auditory stimuli. Next, subjects were told to open their eyes and were presented a SSVEP protocol. Finally they were presented emotionally-charged images and had to perform an emotional categorization task. The instructed mind wandering block corresponded to the exact same tasks as the meditation block, except that in the first part subjects were all performing autobiographical memory recollection for 20 minutes followed by the 13 minutes of the auditory oddball protocol. At the end of each block, subjects answered a questionnaire assessing their experiences during the experiment.

	Vipassana	Himalayan	Isha	Control
Age	47 ± 15	49 ± 13	40 ± 10	45 ± 10
Years of med.	15 (range 5 to 44)	21 (range 3 to 40)	7 (range 3 to 18)	0

Table 7.1: Subject groups mean age and years of meditation experience

Figure 7.2: A subject ready to start the experiment

utes per day.

7.3.3 Data recording

We recorded data using a 64+8 channels Biosemi Active-Two amplifiers system and a 10-20 Headcap montage from the same company. The system also allowed recording respiration and galvanic skin response. Using external electrodes not part of the cap, we also recorded right and left mastoid electrodes as well as vertical and horizontal electro-oculogram two periocular electrodes (EOG) placed below the right eye and at the left outer canthus. The EKG was recorded by placing an external electrode at the collar bone level. A respiration belt was placed just below the navel to record breathing rate and we also recorded the galvanic skin response (GSR) by placing two electrodes on the tip of the left hand index and middle fingers. The experimental room was partially electrically shielded and partially sound proof. In order to ensure good quality of EEG signal participants were asked to wash their hair before attending the recording session and their scalp skin was carefully cleaned using an alcoholic solution just prior to the EEG cap set up. All electrodes were kept within offset 10 of the BIOSEMI system metric for measuring impedance. Figure 7.3.2 shows the placing of the recording equipment on a subject and the arrangement of the experimental room.

7.3.4 Data processing and artifact rejection

Data processing was done using Matlab R2009b (The Matworks, Inc.) and the EEGLAB public software version 10.2.5.5b Delorme and Makeig (2004). EEG data were first referenced to the right mastoid and down-sampled from 1024Hz to 256Hz.

We then applied a high-pass filter at 1Hz using an infinite impulse response (IIR) filter. We automatically removed portions of the signal presenting non-stereotyped artifacts. The data were first segmented in 1-second epochs with 0.5-second overlap. Segments of 8 contiguous epochs in which the 0-10 Hz frequency band and the 35-128 Hz frequency band had an amplitude higher than 17 and 14 decibels respectively were labelled has artefactual. In some cases, decibel thresholds were adjusted automatically to match the tail of the probability distribution of the data. Rejection of low-frequency segments help remove subject's movements. Rejection of high frequency activity helps reject muscular activity. We then manually removed bad electrodes (from 0 to 18 bad electrodes per subject, average of 5 electrodes removed per subject). We finally used Infomax Independent Component Analysis (Infomax ICA) on the pruned data to reject eyes and muscle artifacts. For each subjects we visually identified and subtracted from the data one to five well-characterized ICA components for eye blink, lateral eye movements and temporal muscle noise. We used visual inspection of component scalp topographies and power spectrum to reject these artifactual ICA components Delorme et al. (2007).

In order to compare the effects of different reference montages on the EEG analysis, we successively re-referenced our data to he average reference and the vertex Cz electrode.

For each subject and each of the 4 conditions - breath awareness (MED1), meditation practice (MED2), the first and the last 10 minutes of instructed mind wandering (IMW1 and IMW2 respectively) - we applied a spectral decomposition to the continuous data of each channel. We first segmented data into 1-second long epochs with no overlap, and then performed a Fourrier transformation on these epochs. Fourrier amplitude in different frequency bands was averaged for all epochs. Finally power was visualized by taking 20 times the base-10 logarithm of the spectral amplitude to obtain a scale equivalent to decibel (dB).

7.3.5 Statistics

Statistics were performed on the log transformed spectral power data across channels using the permutation tests implemented in EEGLAB (Delorme and Makeig, 2004). A total of 8 000 resamples of the original data is used to assess significance. When

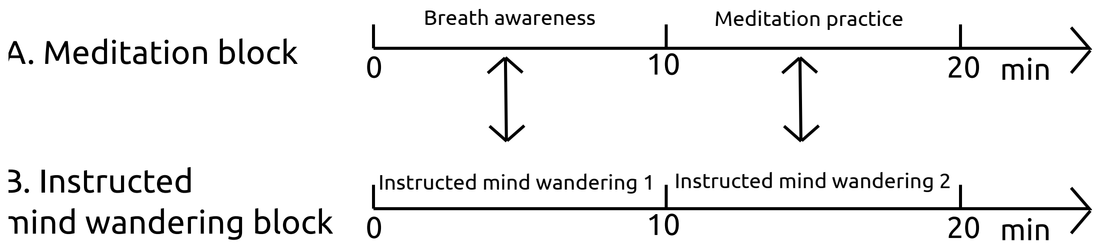


Figure 7.3: Data analysis schematic. For the analysis the first 10 min of the meditation block (Breath) were compared to the first 10 min of the instructed mind wandering block and the last 10 min of the meditation blocks to the last 10 min of the instructed mind wandering blocks.

conditions were compared within a group, permutations of paired t-test were used and when comparisons were made in between 2 groups permutations of non-paired t-tests were used. Finally, for comparisons made between more than two groups across 1 condition we used permutations of balanced 1-way anova and for comparisons between more than two groups and more than 2 conditions, permutations of balanced 2-ways anova. Correction for multiple comparisons was performed using Benjamini and Yekutieli original implementation of the False Discovery Rate (FDR) algorithm (Benjamini and Yekutieli, 2001).

During the recordings of a session, our subjects had to sit for 20 minutes in a row, which were decomposed into 2 blocks of 10 minutes each. To account for any potential effects on physiological measures of simply sitting still for a specific duration of time, we compared blocks of EEG activity between conditions in which the subject has been sitting for an equivalent amount of time (MED1 vs. MED2 ; IMW1 vs. IMW2), see figure 7.3 .

7.4 Results

7.4.1 Subjective reports

Meditators were able to successfully enter a meditative state during the experiment, as assessed by the subjective reports they gave immediately after the meditation block, on a 0 - 10 scale (where 10 indicates the deepest meditative state they have experienced and 0 not deep at all). The HT group reported an average depth of meditation of 6.31 ± 1.88, the ISY group 7.55 ± 1.15 and the VIP group 6.03 ± 1.81.

7.4.2 Comparison between meditation (MED2) and thinking (IMW2)

7.4.2.1 Theta frequency band activity

During meditation (MED2), we found a significant increase in the fronto-central 6-8Hz amplitude in the VIP group compared to the HT group only ($p < 0.005$ over all electrodes). No statistically significant differences were observed between the other groups.

We did not observe differences between groups in the instructed mind-wandering period (IMW2) and we did not observe within groups differences between MED2 and IMW2.

7.4.2.2 Alpha frequency band activity

The VIP group showed significantly higher 8-10Hz alpha frequency range during meditation (MED2) compared to the control group ($p < 0.05$ at all electrodes sites after correction for multiple comparisons), the ISY group ($p < 0.05$ at all electrodes sites) and the HT group ($p < 0.01$ at all electrodes sites).

During the instructed mind-wandering period (IMW2), we observed higher 8-10Hz activity between the VIP and the HT group only ($p < 0,05$, at all electrodes sites). In addition, the 10-11Hz frequency was significantly higher in the VIP group than in the ISY group ($p < 0.05$, at all electrode sites).

Finally, in the HT group but not in the other groups, we observed lower fronto-central and occipital 10-11Hz alpha power during the meditation period (MED2) compared to instructed mind wandering period (IMW2) ($p < 0.05$) (figure 7.4).

7.4.2.3 Gamma frequency band activity

During meditation (MED2), comparisons between the controls and the meditators revealed significantly higher 60-110Hz gamma power in two meditator groups than in the control group: higher 60-110Hz gamma was observed over occipital electrode sites in the ISY group ($p < 0.05$) and over the frontal, midline and occipital electrode sites in the HT group ($p < 0.05$) (figure 7.6). In the VIP group the 60-110Hz EEG band qualitatively displayed higher power than in the control group, and the difference in topography between the CTR and VIP groups was similar to the difference in topography between CTR and other meditation traditions, with greatest effects observed at frontal and occipital sites (figure 7.6 C. However, the difference in gamma activity between the VIP and CTR group did not reach significance. Nevertheless, we observed no significant difference in the 60-110Hz gamma band power between the VIP group

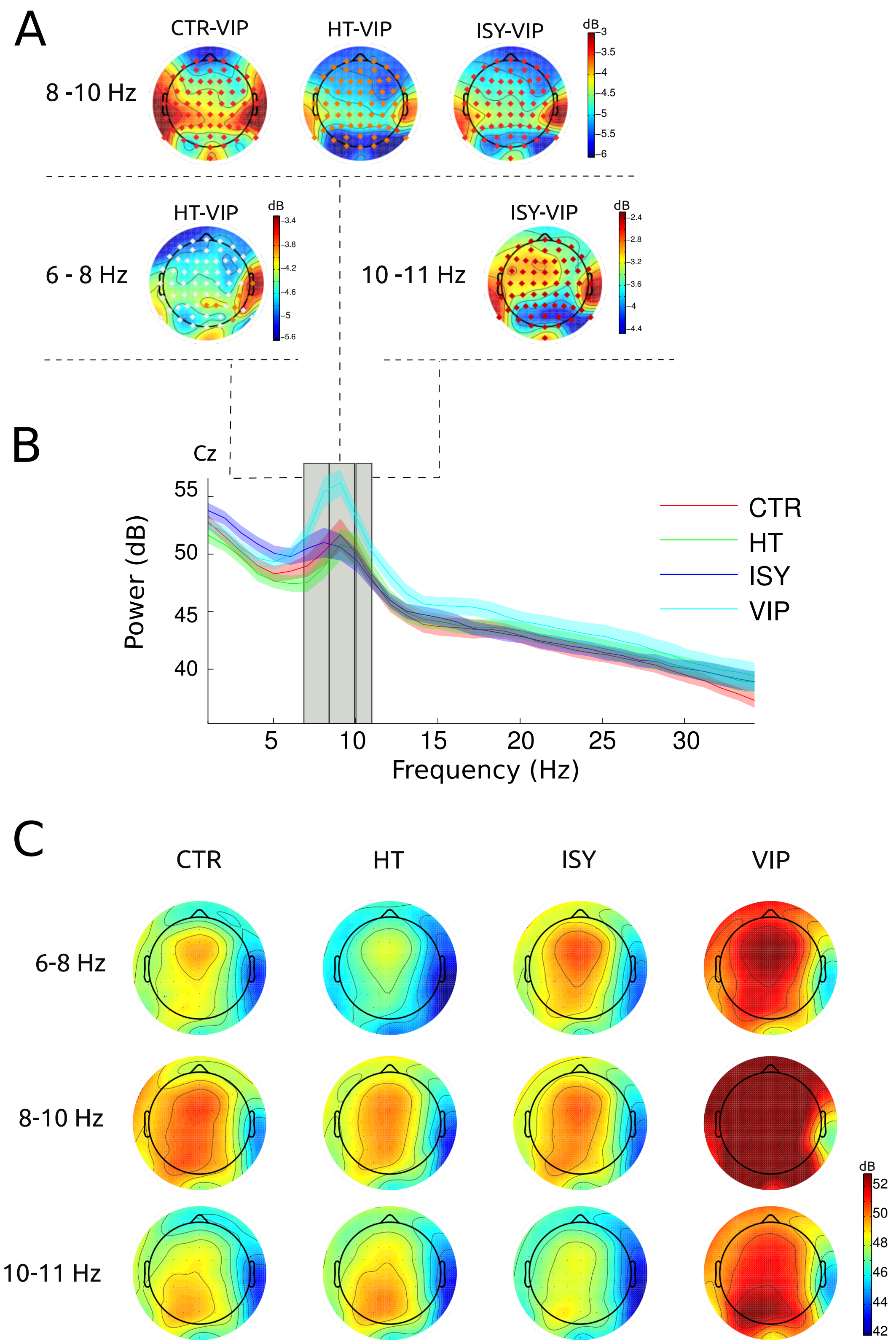


Figure 7.4: Theta and alpha power during the MED2 meditation period. A. Differential scalp topographies between CTR, HT, ISY and VIP for the 6-8Hz, 8-10Hz and 10-11Hz frequency bands. A red dot indicates significance at $p < 0.05$, orange $p < 0.01$ and white $p < 0.005$. B. Spectral activity during meditation for each group at electrode site Cz. Shaded area around the curves represents the standard error of the mean across subjects. C. Scalp topographies for the 6-8Hz, 8-10Hz and 10-11Hz frequency bands (corresponding to the grey area on the power spectrum plot) for each group of subject.

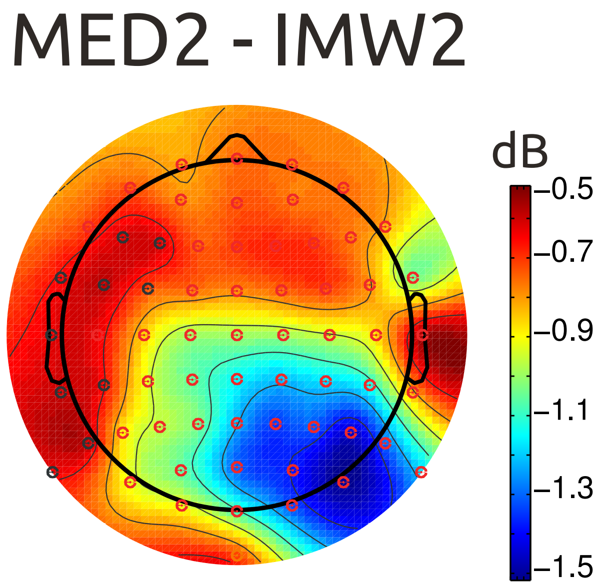


Figure 7.5: Differential maps of group HT 10-11Hz activity between the MED2 meditation period and the IMW2 instructed mind wandering period. Black dots indicate no significant difference at the electrode site and a red dot indicates significance at $p < 0.05$.

and the HT and ISY groups. In addition, when the data of all meditator groups were pooled together, it differed significantly from controls in this frequency band (figure 7.6 B).

We did not observe significant differences between the instructed mind wandering task (IMW2) and the meditation task (MED2) within any of the groups in this frequency band. In addition, during the instructed mind wandering task, we did not observe any significant difference between any of the groups.

Muscle activity is mostly visible at high frequencies, overlapping with the observed effects we report here in the gamma frequency band. In order to assess whether the increased power in the gamma band we observed in meditators was due to cortical or to muscle and other artifactual non-brain activity during meditation periods we used ICA approaches for assessing the data.

Temporal muscle artifacts often contaminate temporal electrodes when recording EEG. 30 temporal muscle ICA components were identified in the 64 subjects (18 right and 12 left temporal muscle artifacts, with between 0 and 2 components per subject) (figure 7.7 B).

Note that these components were removed from the data at the preprocessing stage, before computing the spectral transformation of figures 7.4 and 7.6.

It may be argued nevertheless that residual muscle activity not removed by ICA could be responsible for the gamma effect we observed. However, no significant dif-

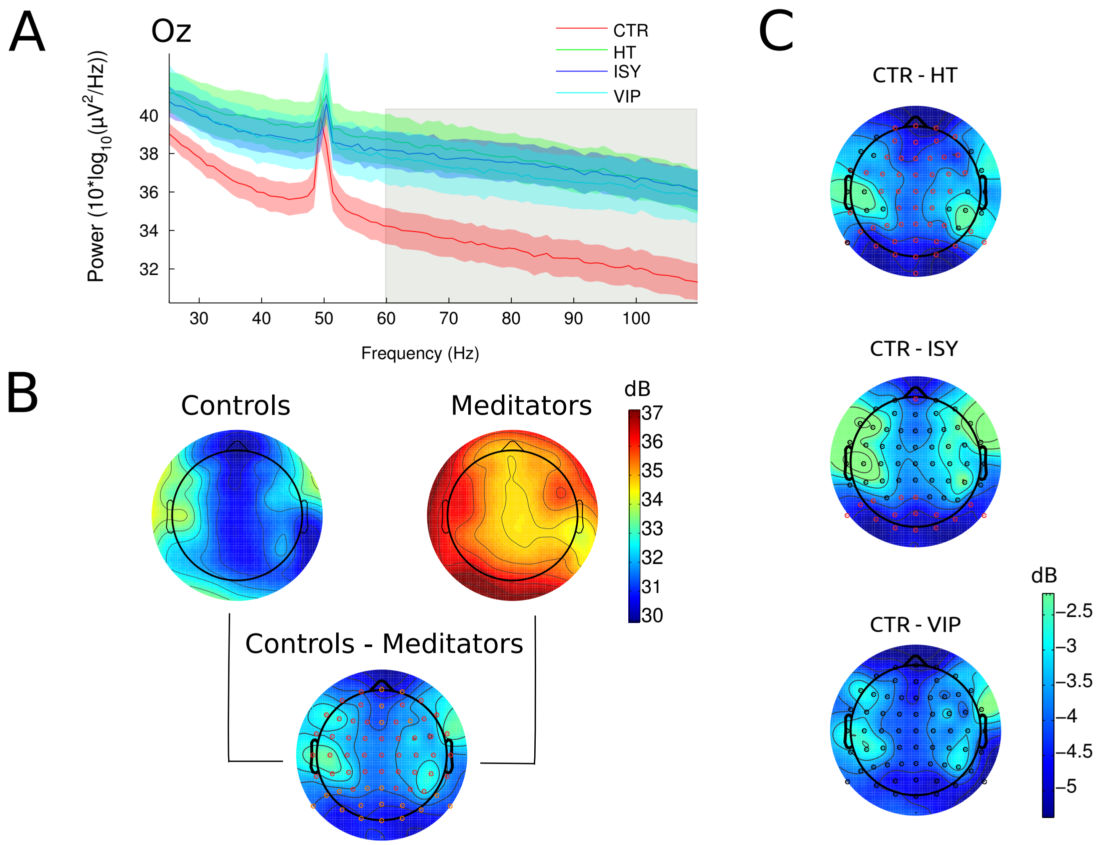


Figure 7.6: Gamma activity during the meditation period (MED2) A. Spectral activity during meditation for each group at electrode site Oz (only the frequency range from 25 to 110Hz is shown). The spectral peak at 50 Hz indicates line noise. Shaded area around the curves represents the standard error of the mean. B. Scalp topographies in the 60-110Hz frequency range (corresponding to the grey area on panel A) for the control groups and all meditators irrespective of their tradition. The scalp topographies of differential activity between the control group and the mean of all groups of meditators is also shown. C. Scalp maps of differential activity between the CTR and each of the meditator groups HT, ISY and VIP in the 60-110Hz range. Note that as these plots indicate control gamma power minus meditator group gamma powers the darker blue represents areas of scalp with greater between group gamma power. A black dot indicates no statistical significance, a red dot an electrode that is significant at $p < 0.05$ at the electrode site and an orange dot indicates significance at $p < 0.01$.

ference of activity between groups and conditions was found in the activity of the temporal muscle artifact components. If muscle activity was responsible for the gamma difference we observed between meditators and control subjects, it should have been visible in these components.

Another hypothesis is that the increase in gamma activity may be generated by the eyes microsaccades. Of our 64 subjects, 53 had one ICA component accounting for eye movements (14 subjects in each CTR, VIP and HT group and 11 subjects in the ISY group) (figure 7.7 A). Eye activity artifactual components are isolated using activity at low frequency (less than 10 Hz). Specific ICA components for eye movement microsaccades did not appear to be isolated either because their amplitude is too small or because their topography is identical to other eye movement components, which is reasonable to consider since they originate from the same location.

Permutation statistics with FDR correction in the 1-120Hz frequency range indicates that there was higher power over all spectral frequencies of the eye movement independent components in the CTR group during instructed mind wandering (IMW2) compared to meditation (MED2) ($p < 0.005$). No significant difference was found in spectral frequency power for the eye movement components between the IMW2 and MED2 states for any of the 3 groups of meditators, nor did we find any significant spectral frequency power differences for this ICA cluster between the 4 groups. If eye movement-related artifacts were responsible for the increased gamma power observed between groups in this dataset, we should have observed higher gamma power in the eye movement independent components for meditators compared to the control group.

These results show that it is unlikely that the gamma power increase we observe in meditators in comparison to control subjects is due to either muscle or eye-related artifacts. In addition, the scalp topography of the differences was greatest in occipital and frontal areas as opposed to temporal areas, further indicating that classic temporal muscle-related artifacts were not likely to be contributing to the observed effects.

7.4.3 Breath awareness (MED1) and instructed mind wandering (IMW1)

The results described below correspond to the first 10 minutes of meditation (MED1) and instructed mind wandering (IMW1). The MED1 period involved the same instruction to focus on the sensations of breath for all groups. Nevertheless, we observed differences between groups in the theta, alpha and gamma frequency bands. We did not observe differences within groups between the breath awareness (MED1) and instructed mind wandering (IMW1).

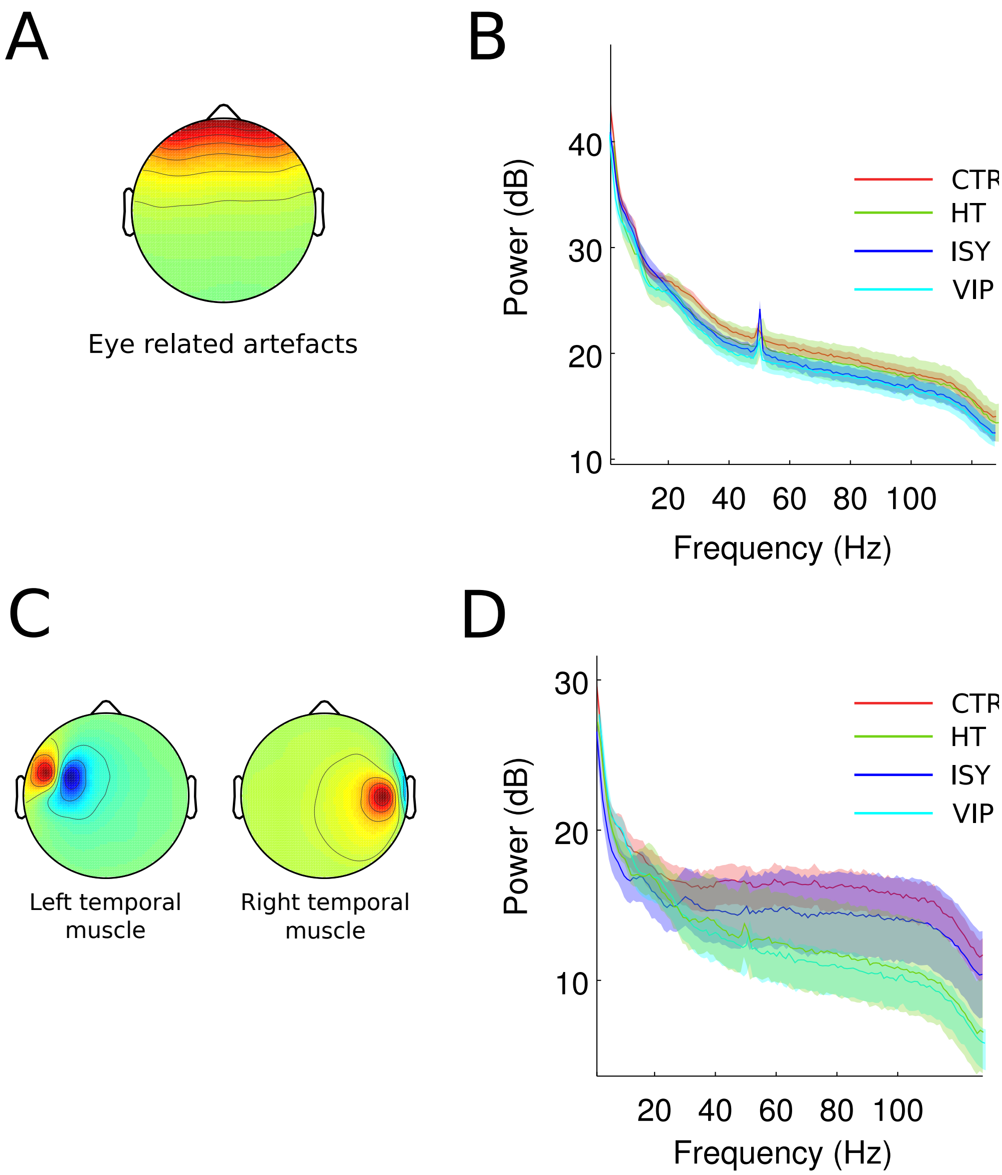


Figure 7.7: Spectral activity of eyes related and muscles related artifacts. A. Scalp topographies of independent component activity for eye related artifacts. B. Vertical eye movement independant component spectral activity in the meditation condition. C. Scalp topographies of independent component activity for left and right temporal muscle activity. D. Pooled left and right muscle ICA component spectral activity for the meditation condi

7.4.3.1 Theta frequency band activity

During MED1, the amplitude of the 4-6Hz low theta frequency range in the HT group was significantly lower than in the VIP and ISY groups ($p < 0.05$, over all electrodes).

The 6-8Hz high theta frequency activity in the VIP group during MED1 was significantly higher than in the CTR ($p < 0.05$, over fronto-central electrode sites) and HT groups ($p < 0.05$, over all electrode sites).

During IMW1 also, the 6-8Hz amplitude in the VIP group was higher than in the HT group ($p < 0.05$, over all electrodes) .

7.4.3.2 Alpha frequency band activity

The amplitude of the 8-10Hz alpha frequency band was higher in the VIP group than in the HT group during both MED1 and IMW1 ($p < 0.05$ over all electrodes).

7.4.3.3 Gamma frequency band activity

In the 60-110Hz gamma range, we observed significantly higher amplitude during MED1 in the ISY group than in the CTR group ($p < 0.05$, at all electrode sites).

7.4.4 Additional results

7.4.4.1 Intra-group comparison between breath awareness and meditation

The comparison between the breath awareness (MED1) and the meditation (MED2) conditions within each group showed in the ISY group higher 8-10Hz alpha power during MED1 compared to MED2 ($p < 0.05$, over all electrode sites).

In addition ISY, HT, and CTR groups all exhibited higher amplitude high alpha (10-11Hz) power during MED1 compared to MED2: CTR ($p < 0.01$, over all electrodes), HT ($p < 0.05$ on occipital electrodes), and ISY ($p < 0.05$ on parieto-occipital electrode sites).

For the ISY group only, beta and gamma effects were found to differentiate MED1 vs. MED2. In this group the 12-20Hz beta activity was higher during MED1 than during MED2 over all electrode sites except for a cluster of 7 fronto-central electrodes (Fz, F1, FC1, FCz, FC2, CZ and C1) ($p < 0.05$). Similar effects specific to the ISY group were found in the gamma (60-110Hz) range, for which the power was again significantly higher during MED1 than during MED2 ($p < 0.05$, over all electrode sites).

To sum up, the most consistent result was therefore that high alpha power decreases in the MED2 compared to the MED1 period for controls, HT and ISY meditators but not for VIP meditators, for which no significant difference appeared between the MED1 and MED2 periods.

7.4.4.2 Intra-group comparison between instructed mind wandering 1 and 2

Comparison between brain activity in the instructed mind wandering periods 1 and 2 (see methods) revealed higher gamma activity (60-110Hz) within the VIP group during IMW1 than during IMW2 ($p < 0.005$, over all electrodes). No significant differences were found in the alpha and beta range for any of the groups between the two instructed mind wandering periods.

7.5 Discussion

The main results of our study are threefold: firstly we showed that, during the meditation period, meditators from 3 different traditions exhibited higher gamma (60-110 Hz) spectral activity over all electrode sites relative to control subjects attempting to meditate. Although it did not reach significance for VIP meditators, a clear trend was observed and the scalp topography difference with the control group was similar to the other meditation traditions. Of note, it is unlikely that this gamma effect was due to eye and muscle artifacts as demonstrated by our analysis of independent components attributable to eye movement and muscle activity showing no difference amplitude across groups. Our second result reflected that Vipassana meditation practitioners exhibited higher power in the theta and alpha frequency bands compared to other meditation groups and control subjects. Finally, we observed a consistent and specific meditation state effect only in the HT meditator group, as indicated by decreased high alpha (10-11 Hz) power in the meditation vs. instructed mind wandering tasks.

7.5.1 Gamma activity

Our gamma results are generally consistent with a small number of recent studies indicating enhanced gamma power associated with meditation in long term practitioners, although in these studies the frequencies of the gamma activity were lower than in the present report . Higher occipital 35-45Hz gamma activity was previously observed as a specific state effect in Vipassana meditators (Cahn et al., 2010) while meditating compared to a control condition of instructed mind wandering similar to ours. In addition, Tibetan Buddhist meditators also showed increased 25-42Hz gamma power during loving-kindness meditation (a meditation based on the feeling of compassion towards all other beings) compared to control subjects as both a trait and state effect

(Lutz et al., 2004). It is relevant to note that in general other EEG studies of meditation are not analyzing fast frequency rhythms most probably due to technical limitations.

This broadband gamma effect was found not as a specific state effect of meditation in the meditator groups but as a mixed trait-state effect that was greatest in the Isha Yoga meditation group and was significant specifically when comparing brain activity in meditation periods across groups but not when assessing control state activity across groups. Specifically, comparisons between mind wandering periods and the meditation periods within groups indicated no specific meditation state effect in the gamma range for any of the groups. In contrast, comparisons of gamma power across the first breath focused period showed the Isha yoga meditation group to have greater gamma power compared to control group. Comparisons during the second meditation periods wherein each meditator group engaged in their own specific meditation practice yielded significant increase of gamma power in Isha yoga and Himalayan yoga groups compared to the control group, with the Vipassana group showing a very strong trend in the same direction. Moreover, the Isha yoga group also showed a greater gamma power during the breath-focused first meditation period than the second Shoonya meditation period.

In the litterature, there is no clear understanding of the functional role of EEG gamma activity, which requieres the synchronous activation of large populations of neurons. Physiological studies support the hypothesis for a role of gamma synchronization in neuronal communication (Salinas and Sejnowski, 2001; Fries, 2005; Varela et al., 2001). This hypothesis has been further supported by the finding of a link between regions of fMRI activation and intra-EEG gamma activity recording (Lachaux et al., 2007). Lutz et al. (2004) suggested that the gamma band activity observed in the meditators engaged in loving kindness meditation might reflect specific affective and attention processes. There was no strong affective component in the meditation practices we studied, however it might be that the gamma activity we observe, also of higher frequency than in Lutz et al. (2004)' s study reflect different attention processes in meditators. Indeed, studies in the field of visual attention have shown that voluntary allocation of attention towards stimuli increases the gamma response compared to unvolontary, stimulus-driven attention (Landau et al., 2007). We can thus hypothesize that the gamma activity we observe over the frontal areas in HT meditators results of more top-down control of attention in these meditators than in controls. This top-down control will be exerted to redirect the attention towards the meditation in case of mind wandering episodes and to ignore distracting stimuli such as pain that can arise in the body from the continuuous seating position or external noises. In addition, we also report gamma activity over the occipital regions in HT and ISY groups. Occipital gamma activity in Vipassana meditators is also reported by (Cahn et al., 2010), although again at a lower frequency than in our study. Gamma activity over the occipital lobes have been associated with visual grouping processing and visual representation (Vidal et al., 2006; Lachaux et al., 2005; Jokisch and Jensen, 2007) and with sustained attention (Tallon-Baudry et al., 2005). It thus possible that the occipital gamma activity reflects both different attentional processes and specific visual representations, for example of different body points (chakras) for the HT meditators. For the ISY tradition however, it is not clear what kind of representation might be elicited by the meditation.

Of note, gamma activity in EEG has also recently been associated with eye tremors and microsaccades in addition to the well known association with scalp and temporal muscle activity (Yuval-Greenberg and Deouell, 2009; Schwartzman and Kranczioch, 2011), thus rendering suspicious gamma findings in EEG studies. Gamma activity induced by microsaccades is most prominent when using the nose as reference and we used here mastoid reference, which is likely to be weakly contaminated by microsaccades. More importantly, we analyzed the ICA components associated with eye and scalp muscle noise to assess the possibility that the observed gamma power differences may be spurious. We did not find differences between meditators and controls in the eye movement or temporal muscle independent component activities suggesting that the higher gamma amplitude recorded in the meditator groups does not rise from scalp muscle or ocular activity.

7.5.2 Alpha activity

We found a trait-related increase in amplitude in the alpha frequency band during meditation that was specific to the Vipassana group and became more significant during the assayed meditative states. Specifically, during the mind wandering control state the Vipassana group showed higher amplitude 8-10Hz power than the Himalayan yoga group and during the second mind wandering state the Vipassana group demonstrated higher amplitude 10-11Hz power than the Isha yoga group. During the breath-focused meditation period the Vipassana group again showed higher amplitude 8-10Hz power than Himalayan yoga group, and finally, during the specific differential meditation period the Vipassana group showed higher amplitude 8-10Hz power than control group, Himalayan yoga group, and the Isha yoga group.

To our knowledge, there is no previous study showing increased alpha frequency amplitude in Vipassana meditators compared to other meditation traditions (for a recent review, see Chiesa and Malinowski (2011)). Cahn and Polich (2006) reviews the literature regarding reports of increased alpha amplitude in a variety of meditation practices when compared to control states, although none of these studies included Vipassana meditators. Moreover, increases in alpha power are not reliable state markers of meditative states Cahn et al. (2010) and in line with our previous results Cahn et al. (2010), we did not find significant differences between alpha amplitude during meditation and the control task in the Vipassana group.

A common hypothesis suggests that alpha activity increases during "cortical idling", when neurons are not actively processing sensory inputs (Pfurtscheller et al., 1996; Mann et al., 1996). This hypothesis is related to the fact that closing ones eyes dramatically increases alpha power. However, increases of alpha power have also been observed in tasks requiring the redirection of attention internally, for example when subjects are asked to imagine a stimulus, leading to the hypothesis that alpha power inhibits irrelevant sensory inputs (Cooper et al., 2003). Following this hypothesis, the finding that alpha activity seems to be increased in those practicing Vipassana meditation may be related to the type of focus this form of meditative practice requires. One might hypothesize that the way of attending to the specific somatosensory awareness task involved in this form of Vipassana practice while ignoring other types of sensory inputs may increase one's internalized focus in a more significant manner than is engaged by the other assayed practices. In fact, inhibiting irrelevant sensory inputs might not be as important in other meditation traditions, where attending selectively to some types of endogenous sensory stimulus to the exclusion of others is not a central focus of the practice. The current findings do suggest that regular practice of Vipassana meditation induces higher trait amplitude in the alpha frequency band although it is also possible that individuals with higher trait alpha power have a predilection for taking up Vipassana practice - only controlled longitudinal trials involving different meditative practices can satisfactorily answer this question.

Within the HT group we found lower high-alpha power (10-11Hz) during the specific meditation practice compared to the corresponding instructed mind wandering task. In line with the theory mentioned earlier that alpha may index "cortical idling",this finding suggests that Himalayan yoga meditation practice was characterized by greater cortical processing during the meditation task compared to the IMW task. Interestingly, decrease of 8-12Hz alpha frequency is also found during sleep stage 1 (De Gennaro et al., 2001) and earlier studies of meditation have suggested that meditators appear to maintain their brain state at a transitional level between full wakefulness and early sleep stages (Fenwick et al., 1977; Stigsby et al., 1981). It is possible that the assayed Himalayan meditation practice leads to this type of state, given that the Yoga Nidra practice (sleep of the Yogi) is an important component of the HT practice. Further studies of this meditation tradition focusing on Yoga Nidra practice and including precise metabolic recordings would be able to test this hypothesis more precisely. The control and the Isha Yoga groups did demonstrate higher alpha 10-11Hz power during the first 10 minutes of the breath awareness phase than during the meditation phase as well, suggesting that the decreased alpha power obtained during the second meditation phase in the HT group may have been a relatively non-specific effect.

7.5.3 Theta activity

During meditation the VIP group demonstrated greater fronto-central 6-8Hz theta activity than the HT group. We did not observe a clear spectral peak in the theta frequency band and our theta results could reflect a smearing in the frequency domain of the high power alpha frequency peak observed in VIP meditators. However, the distinct scalp topography for the 6-8 Hz activity with a more frontal component typical of theta frontal midline activity (Onton et al., 2005) compared to the more occipital activity in the 10-11 Hz frequency band argue against this hypothesis.

Frontal increase of theta activity has been reported in a variety of meditation practices (for example Aftanas and Golocheikine, 2001; Arambula et al., 2001; Lagopoulos et al., 2009; Baijal and Srinivasan, 2010). Frontal midline theta rises from activity of the medial prefrontal and anterior cingulate cortex (Asada et al., 1999; Ishii et al., 1999) and have been found to increase with task requiring attention and working memory (Onton et al., 2005; Scheeringa et al., 2009; Lazarev, 1998; Smit et al., 2004). These results suggest that mental effort during meditation could be higher for our group of Vipassana meditators than for the group of HT meditators.

7.5.4 Specific markers of meditative state in different traditions

With regards to the effects comparing between the breath awareness practice (MED1) and the subsequent meditative period (MED2) it is important to note that MED2 was always recorded after MED1 so this comparison does not take order effects into account. It is possible that the differences observed between these states correspond to non-specific effects related to the passage of time in eyes-closed conditions and is not specific to the practice involved. Despite this limitation, the fact that different trends in different groups were observed argues for some specific effects related to the different practices engaged. As mentioned above both the CTR, ISY and HT groups demonstrated higher 10-11Hz power during the MED1 (breath awareness) compared to the MED2 (specific meditation) periods. In addition, the Isha yoga group demonstrated higher power in the MED1 periods across lower alpha (8-10Hz), beta (12-20Hz), and gamma (60-110Hz) frequency ranges. No change in any frequency band power was found comparing between the two conditions for the VIP group.

The fact that no differences were obtained between the breath awareness and somatosensation / open-monitoring periods in the Vipassana group may be related to the way in which these two practices are taught in tandem in this form of practice. Breath awareness is often used at the start of Vipassana meditation practice to focus the mind and it is possible that the VIP group could not refrain from entering a fairly equivalent breath / somatosensation / open-monitoring meditative state regardless of the instruction as these three different aspects of the technique are incorporated strongly into the learning of the practice in this tradition.

To sum up, we have shown that a daily meditation practice induces trait changes in brain electrical oscillations. These changes vary from one meditation technique to another and our results emphasize the need to include control participants and if possible several groups of meditators from different traditions in each meditation study. Given the absence of clear contrast between the EEG spectral activity during the meditative and the instructed mind wandering states (state differences as opposed to trait differences), we suggest that meditation might be a subtle state that is not too different from other mental monitoring activities – and would involve the same type of mental structures and mechanisms. Future studies should also determine what could be the best control mental state for meditation. In addition, other types of EEG analysis, such as measures of synchrony might be worth trying to unveil other potential differences between meditation and other mental states.

Part IV

Conclusion

Chapter 8

Conclusion

Contents

8.1 Synthesis of the results and general discussion

This thesis aimed at characterizing the EEG neuronal substrate of two attentional states, mind wandering and meditation. My work introduced this new thematic in a research team and laboratory that were more specialized in the study of visual perception than of subjective states. Since I started this PhD, the interest of the scientific community for mind wandering and meditation has kept growing. However there is still much to do before we obtain a clear understanding of the mind wandering and meditation conscious states.

8.1.1 EEG correlates of mind wandering

While previous work on mind wandering has investigated mainly the context in which it occurs and the neural correlates through fMRI or ERPs study, we have tackled for the first time the dynamic of the EEG oscillatory activity during mind wandering (chapter 3). We designed an original protocol to collect occurrences of mind wandering based on the subject's inner experience. Noticing from our own experience that simply trying to observe our breathing for a continuous period of time was already challenging, we asked our subjects to continuously count their breath from 1 to 10 and to press a button each time they noticed they had stopped doing the task. This method allowed us to obtain spontaneous reports of mind wandering events. In addition to this task, subjects were listening to an auditory oddball protocol. Importantly, subjects participating to this study were all naive to the practice of meditation .

Using EEG time-frequency analysis, we have shown that periods of mind wandering, defined as the 10-seconde period preceding a button press, are accompanied by increase amplitude at low frequency bands 2-3.5Hz delta and 4-7Hz theta. By contrast, the 10-seconde period following a button press, when subjects were focusing back of the breathing task, are characterized by increased amplitude in the alpha band, and decreased amplitude in the theta and delta frequency bands (figure 3.2). The ERPs elicited by the frequent and rare auditory stimuli allowed us to characterized sensory processing during mind wandering in comparison to the periods of breath concentration (figure 3.6). The pre-attentive negative component of the ERP at about 100ms after presentation of a stimulus was reduced during mind wandering, indicating a decrease in sensory processing.

Based on these results and the vigilance/sleep literature (see chapter 3), we suggested that occurrences of mind wandering are accompanied by a decrease in vigilance level, resembling an early stage of drowsiness.

8.1.1.1 Control task and novelty of the experimental design

The control task being used to study mind wandering was critical. We chose a breath focus task, which is a relatively neutral non-cognitive task. Ideally, one would study mind wandering during several control attention engaging tasks. Here, we want to emphasize the difficulty and novelty of the experimental design and why it was impractical for us to use multiple control tasks. Other studies of mind wandering often use tasks where subjects have to respond continuously to stream of stimuli (e.g. (Smallwood et al., 2008)) and Smallwood et al. (2006) place a distinction between self-caught and probe-caught mind wandering episodes. In probe-caught mind wandering protocols, to assess the amount of time subjects spend mind wandering while being unaware of it, they may be probed at regular intervals about their state of mind wandering. Self-caught mind wandering is the type of mind wandering studied in this report. In our task, we asked subjects to press a button based on pure introspection. We wanted to collect as many behavioral responses as possible, but despite one hour of recording for each subject, we only obtained 13-52 clean data epochs per subject corresponding to a mind wandering episode. In addition, despite the instruction to stay still, subjects tended to have muscle artifacts in their EEG after pressing the button, forcing us to reject about 25% of the data. Finally, subjects varied widely in their propensity to report mind-wandering events, and four subjects had to be excluded because they provided too few responses. This experiment was the first of its kind and is a proof of concept that, despite the difficulty encountered, this type of study is possible.

8.1.1.2 Why do we experience mind wandering ?

The functional role of mind wandering remains debated in philosophy and experimental psychology. The concept of mind wandering plays an important role in Buddhist psychology (Trungpa, 2004) since it is a major obstacle to concentrative meditation practice. Buddhist psychology argues that mind wandering is a non-productive ego-centered state, a state of "sleep" where our unconscious constantly rehash the same thoughts and beliefs creating confusion and strengthening our sense of self. By contrast, some researchers have suggested that mind wandering may be useful to provide creative insight (Christoff et al., 2009) in a way similar to sleep-induced insight (Wagner et al., 2004). Our result of finding mind wandering to be a state of low alertness supports both views. It can be considered a state of low concentration or relative "sleep" as argued in Buddhist psychology but it could also be seen as an hypnagogic state that may lead to creative insights (Boynton, 2001).

Interestingly Christoff et al. (2008) has also speculated that mind wandering would be the phenomenological experience of off-line processing occurring during wakefulness, the same way that when asleep, dreams are thought to be expression of memory consolidation processes through reactivation of experiences. Indeed, off-line processings of experience contributing to memory consolidation that are known to occur during the different sleep stages (Peigneux et al., 2001; Stickgold, 2005; Wamsley et al., 2010) would also be present during wakefulness (Peigneux et al., 2006; Robertson, 2009).

Christoff et al. (2008)'s proposal can also be integrated within theories of mind wandering involving executive attentional control. Executive control is notably involved in self-regulation, that is our ability to control our thoughts, feelings and behaviors (Petersen and Posner, 2012). In their review, Smallwood and Schooler (2006) proposed that mind wandering would be a disengagement of executive control from the primary task to redirect the attention towards processing of internal information. This internal information might thus be arising as side effect of ongoing off-line memory processes.

Lutz et al. (2008b) have suggested that long term meditation training could enhance the capacity to inhibit introspective spontaneous activity during sustained attention engagement through the modification of large-scale neuronal network connectivity and activity. With regards to Christoff et al. (2008) and Smallwood and Schooler (2006)'s proposals we suggest that meditation training increases executive control to prevent the automatic redirection of the attention toward the phenomenological contents of the experiences being re-activated by off-line memory processing.

In the view of our results suggesting that mind wandering is a state of early drowsiness, Christoff et al. (2008)'s theory is particularly interesting as it creates a parallel between mind wandering and dreams and suggest a relationship between the vigilance state and memory processes. Further studies should investigate possible link between attentional and memory processes as well as the possible relationship between dreams and mind wandering.

8.1.2 Perspective in mind wandering research

As we have seen, research on the mind wandering phenomena is a fast growing field (see figure 2.1). To ensure the reliability of cross-studies comparisons, researchers will have to develop common concepts to account for the experience of mind wandering. The recent paper from Christoff (2012) attempts to make the first steps in this sense but we have seen in chapter 2 that a clear classification of thoughts remains difficult.

Given the wide variety and diversity of mind wandering experiences, we suggest that adopting a phenomenological approach will greatly help in the definition of mind wandering within a study. In chapter 4 we have presented our first attempts towards developing working methodologies to study the phenomenology of mind wandering. Although preliminary, our first results with the explicitation interview technique highlight the high variability of experience of mind wandering. The detailed questionnaire used in the EEG-oculometric study was an attempt to account for this diversity and allow the subject to give a rather detailed description of the charecteristics of the mind wandering event he has just experienced. A few studies have equally already developed a similar detailed experience sampling approach. For example, Stawarczyk et al.

(2011a) have used a questionnaire to define the "stimulus-dependency" and "task relatedness" of their subject's thoughts. We expect that the use of phenomenological reports in the study of mind wandering will develop, giving the possibilities for accurate analysis of mind wandering in neuroimaging studies and will improve the reliability of cross-studies comparisons of the effects of mind wandering.

8.1.3 Comparative study of the EEG activity in meditation

In meditation practices, awareness of mind wandering is critical as they take the mind away from the meditation practice. Any time an attentional lapse is recognized, the meditation practionner redirect his mind towards his meditation. Scientific literature on meditation indicates that meditation practice in general seems to have a positive impact on both physiological and psychological health (see chapter 6). However, we were unable to find any clear consensus as to why this is the case. More specifically, at the physiological level, researchers have not been able to isolate a common EEG signature of meditation in different meditation practices. Was this because of a real absence of common EEG features between meditative practices - or even meditation practitioners - or was it due to differences in studies protocols and recording conditions. To start answering this question, we designed a study aiming at comparing the EEG activity of practitioners of different traditions of meditation, recorded in the same conditions (chapter 7).

Different meditation traditions make different use of attention focus and mental imagery. Within the scientific community meditation practices are usually classified along a continuum ranging from focused to unfocused attention. In addition practices can include the mental repetition of a given sound (or mantra) or evocation of certain mental images. For our comparative study, we have included expert practitioners from meditation traditions with distinct characteristics (chapter 7). Although our choices were constricted by time, economic and social constraints - the study took place in India and we had to make appropriate contacts to recruit our participants - we were able to recruit 27 subjects from a mantra-based meditation (Himalayan Yoga), 20 from open monitoring attention (Vipassana) and 20 from a passive meditation, *i.e.* requiering no concentrative effort or active control (Isha Yoga) in addition to 32 meditation naive subjects forming a control group. For the purpose of data analysis subjects were paired for sex and age, forming 4 groups of 16 subjects each.

The comparisons of the mean frequency band content of the EEG between these 4 groups indicates a common increase of the amplitude of fast frequencies gamma (60-110Hz) in the meditator groups during the meditation condition (figure 7.6). The careful inspection of activity from ocular and muscular movements dismissed the hypothesis that the observed gamma activity originates from artefactual sources (see figure 7.7).We have discussed these results as reflecting different top-down attentional engagement and processing in meditators compared to controls. We also found increase amplitude of the 8-10Hz alpha in the Vipassana group compared to the all other groups which we interpreted as higher attentional selectivity in this group.

Intrestingly, we found no state effect: no significant difference was found between the meditative and the instructed mind-wandering (IMW) task we used as a control mental state, questionning the relevance of instructed mind wandering as an adequate control task for meditation.

8.1.3.1 The choice of a control mental state for meditation

Meditation practice requires the practitioner to disengage from the processing of the self-centered spontaneous thoughts that are considered as naturally produced by the brain in the resting state (Christoff et al., 2009; Raichle et al., 2001; Killingsworth and Gilbert, 2010). An ideal control state would have been to let our participants engage in mind wandering while resting, since according to our previous study, neural correlates of mind wandering are quite distinctive from those of a meditative activity (Braboszcz and Delorme, 2011). In fact, the resting state is a control condition often used in the meditation litterature (see for example Travis and Wallace, 1999; Khare and Nigam, 2000; Arambula et al., 2001; Aftanas and Golocheikine, 2001; Lutz et al., 2004). However, experienced meditators also often report spontaneously engaging in meditation when sitting with no specific task to execute. The instructed mind wandering task was chosen as it requires to keep the mind involved with episodic memories (Cahn et al., 2010; Cahn and Polich, 2009), a phenomenal state that is quite different from the one in (successful) meditation.

Thus our analysis compares the meditative state to a state of active retrieval of autobiographical events. The results we presented are then likely to reflect the EEG activity due to differences in the attentional focus and in the semantic and memory processings of the brain. Of note, there is no similarity between the EEG frequency content of the instructed mind wandering state and the one of the spontaneous mind wandering events of our first experiment (chapter 3), which is easily understandable as IMW does not does not involve the physiological changes associated with spontaneous mind wandering.

The fact that we observed a difference between meditation and instructed mind wandering in only one frequency band and in only one group (see figure 7.4) might reflect that the same type of structures are active during the two mental states. In fact, both states require the monitoring of one's own mental activity. The difference lies in the internal attitude subjects adopt towards the thoughts: during meditation they have to keep a non judgmental attitude of acceptance toward the present experience and not attempt not to get distracted by thoughts (Bishop et al., 2004). By contrast, during IMW they are explicitly told to let their mind freely wander through their memories. It is possible that during the IMW task some of our meditators kept the non-judgmental attitude towards their experiences as if they had been meditating. It is also possible that some of our meditators failed to follow instructions and had episodes of meditation during the control task and episodes of mind wandering during the meditation task. We have reported subjective judgement of subjects regarding the quality of their meditation (see paragraph 7.4.1) which indicates that in all groups subjects were able to reach a satisfactory meditative state. Unfortunately, we do not have equivalent reports of judgements regarding the instructed mind wandering session which could have indicate wether meditators had episodes of meditation during the control task or not.

In another line of research protocoles have sometime used contrast between different meditative states within the same subjects. This protocol design, employed for example in the studies by Lutz et al. (2004) or Carter et al. (2005), requieres however to study expert practitioners of meditation traditions in which it exists precise description and training of different states, such as in Tibetan Buddhism.

8.1.3.2 The importance of the EEG reference montage on data analysis

The choice of reference can have substantial effect on EEG data analysis. Previous studies reporting meditation-related gamma activity have used diverse reference montages such as the vertex electrode Cz (Lutz et al., 2004) and linked earlobes (Cahn et al., 2010).

For the meditation study, to complement our data analysis using the right mastoid as a reference, we analyzed the data using the average reference method as well. The significance for the alpha peak for Vipassana meditators was preserved. However in the gamma band during the MED2 period, the difference did not reach significance between the control and the meditator subjects. The activity of independent component related to eye and muscle artifacts did not differ from the one observed using the mastoid reference. Note that we computed ICA artifactual components using the mastoid montage and re-referenced the components to average reference montages. It is possible that running the ICA algorithm on the average reference montage would isolate better components for that montage – although it was impractical in our case since it would involve re-selecting ICA components and we wanted to be sure to remove the same ICA components in all cases. Recently, a comparative study of the effects of 4 different reference montages on the EEG characteristics show that the single mastoid reference would consistently show the largest power spectra values whereas the average reference would consistently show the smallest (Qin et al., 2010). This suggests that the mastoid montage might be more sensitive, and this could explain our results where the gamma difference reaches significance using the mastoid montage but not with the average reference one. The ideal reference – something that has not been achieved so far to our knowledge – would be a perfectly neutral reference not influenced by brain signals: this is not achieved either by the mastoid or the average reference (Nunez and Srinivasan, 2006; Ferree, 2006).

8.1.4 Integration of mind wandering and meditation in a general model of conscious states control

I will now show how mind wandering and meditative states fit in the brain-mind states continuum outlined in Hobson's AIM (Activation- Input-ouput gating- Modulation) model (Hobson, 1992). The AIM model has mainly been developed based on neurobiological aspects of the waking and sleeping states. Although first established in Hobson (1992), we will base our description on more recent accounts from Hobson et al. (2000) and Hobson (2009). The three dimensions of the model are based on factors known to variates with states of consciousness. It is important to note that this model has been originally developed based on knowledge of the brain activity during the different states of consciousness that are the waking, REM sleep and non-REM sleep states, which have been first study in animals before being able to use neuroimaging technologies in humans.

Activation refers to the information processing capacity of the brain, *input-ouput gating* refers to state-dependant changes in the access of the brain to sensory information from the external environment and the capacity for the brain to transmit motor commands to the body. Finally, *modulation* refers to the neurochemical activity that originates from neurons of the brain stem by releasing of dopamine, noradrenaline, serotonin acetylcholine.

Figure 8.1.4 shows Hobson (2009)'s AIM model of brain-mind state, with an emphasis on sleep states. The 3 factors described above are the 3 main axes of a cube which trace a state space model.

How could the meditation and mind wandering states fit into this model? Let's consider the experimental results we have obtained on these two states how they may relate to the AIM model dimensions.

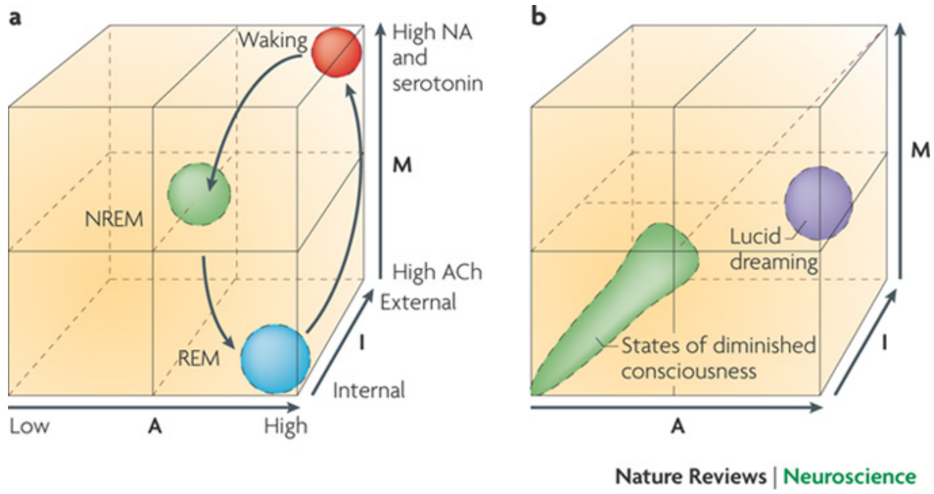


Figure 8.1: Hobson (2009)'s model of brain-mind state control. The model is created and the brain-mind states places based on animal and human experiment data (for dimension activation A and input-output gating I) and based on animal experiment only for dimension modulation M. Ach:acetylcholine; NA: noradrenaline; NREM: non rapid-eye movement sleep; REM: rapid eye movement sleep.

8.1.4.1 Mind wandering state

- *Activation:* there is no results indicating a changes in the information processing of the brain during the mind wandering state compared to normal waking state. Instead, it has been proposed that during mind wandering the information processing is decoupled from the primary task (Smallwood et al., 2003). Thus we will consider that there is no significant changes in *activation* between normal waking and mind wandering.

- *Input-output gating:* there are experimental evidences of a decreased sensory processing of external stimli during mind wandering compared to a non - mindwandering state (Smallwood et al., 2008; Kam et al., 2011; Braboszcz and Delorme, 2011, see). In consequence, mind wandering will have a lower value on the I axis than wake.

- *Modulation:* a recent study by Smallwood et al. (2011) linked mind wandering episodes with increased pupil diameter, a result that we have also found in our own laboratory (Grandchamp et al., 2011, unpublished data). Pupil diameter is often used as a marker of the noradredrenaline system activity and Smallwood et al. (2011, 2012) have suggested that higher tonic noradrenaline would facilitate mind wandering. This hypothesis is based on the Adaptative Gain Theory which assumes that gain on cortical processes increases under the action of the locus coeruleus (in which noreprinephrine is produced) and that cognition can be bias towards or away from information relevant to an external task depending on the level of temporal coupling between the activity in the locus coeruleus and events in the current task (Berridge and Waterhouse, 2003; Aston-Jones and Cohen, 2005). Thus during mind wandering, there will be increased firing rate of the locus coeruleus leading to increased release of norepinephrine compared to normal waking state.

8.1.4.2 Meditation state

- *Activation:* higher gamma activity has been reported during meditation state in expert Tibetan Buddhist practitioners (Lutz et al., 2004), Vipassana (Cahn et al., 2010), and Himalayan Yoga, and Isha Yoga meditation (see chapter 7). EGG gamma activity is supposed to be related to local neuronal communication (Fries, 2005; Varela et al., 2001). Consistent with this hypothesis, link between regions of fMRI activation and recording of intra-EEG gamma activity have been found (Lachaux et al., 2007). We may thus consider that, because of higher gamma activity compared to the normal waking state, meditation might correspond to a state of higher information processing capacity, that is higher *activation* in the AIM model.

- *Input-output gating:* using an auditory oddball protocol, Srinivasan and Baijal (2007) showed that, for participants with 3 to 7 years of daily practice of a form of concentrative meditation, pre-attentive perceptual processes was enhanced in meditators following meditation practice compared to a control group practicing relaxation. By contrast, also using an auditory oddball protocol although this time in expert Vipassana meditators, Cahn and Polich (2009) observed a reduction of the attentional engagement in response to the oddball stimuli as well as a general decrease of sensory response to stimuli during meditation compared to a control mental state within the same subjects. Thus there might be an effect of the meditative state on processing of external stimulation that depend on the type of meditation. In addition, processing of external stimulation might vary depending on the level of meditation expertise of the practionners, or even within a meditation session.

- *Modulation:* although early studies have investigated neurochemical effects of meditation on the brain, mostly during transcendental meditation practice, there is no clear evidence for a shift towards higher or lower noradrenaline or acetylcholine levels during meditation. More recently, studies of Vipassana meditation (Nagendra et al., 2012; Tooley et al., 2000) have found increased levels of melatonine following the practice. Since melatonine is synthetized from serotonine we may hypothesized that Vipassana meditation induce increased released of serotonine.

8.1.4.3 Integration to the AIM model

Based on the data and hypothesis listed above, we suggest to introduce the mind wandering and meditation states in the AIM model as in figure 8.2. Given that, as revealed by the divergent results regarding the "input-output gating" dimension in the meditative state, different forms of meditation may lead to different effects, we only considered in the model the case of Vipassana meditation, as it is the only tradition for which wecould gather data for all 3 AIM factors.

Although much work is still needed to confirm this preliminary model of the mind wandering and meditation states, we believe integration of these states in a more general model of consciousness is one step further towards the understanding of the human mind in its diversity of experiential states.

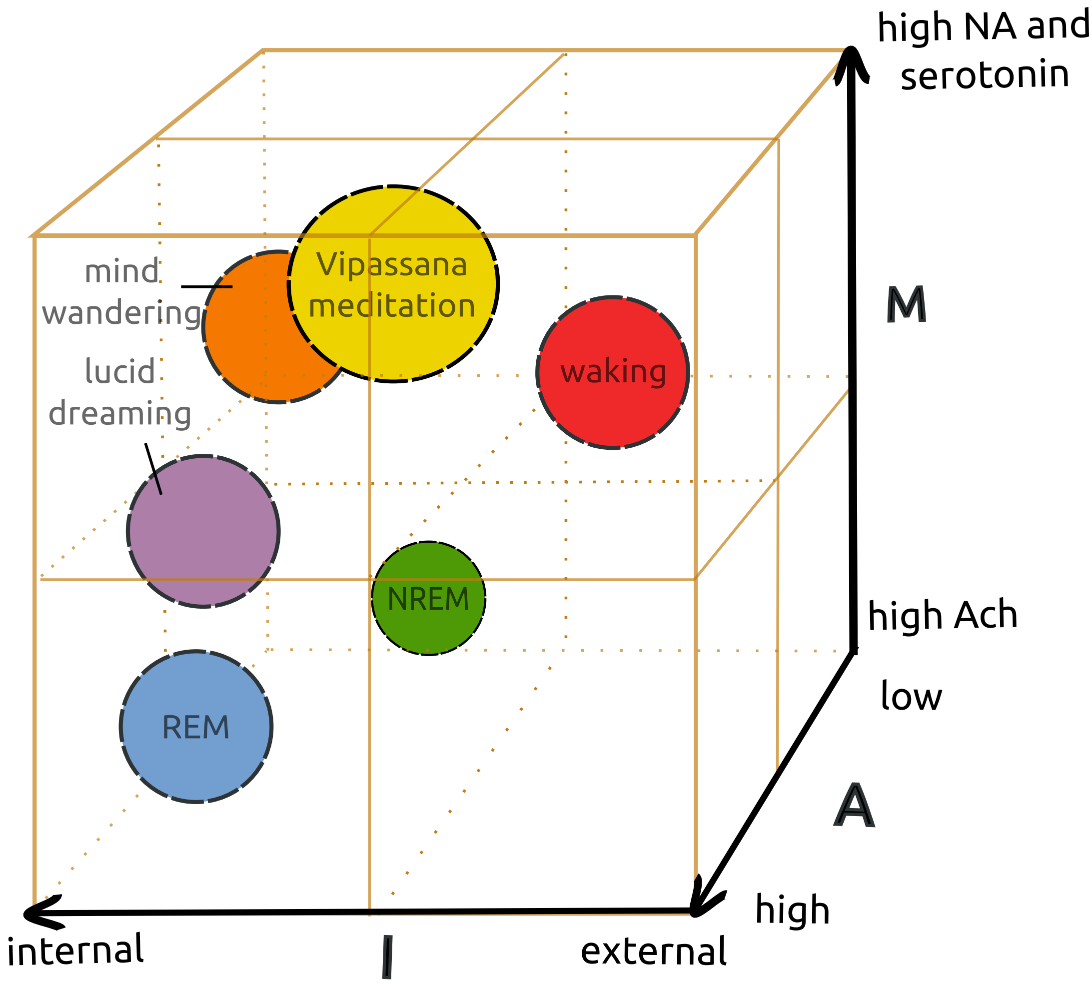


Figure 8.2: Adaptation of the Hobson's model of the conscious state continuum (Hobson, 2009) with integration of the mind wandering state and Vipassana meditation state. The axes have been shifted to allow a better visualization. Mind wandering occurrences have been linked to increased activity of the noradrenaline system while external sensory input is limited during mind wandering in favour to increase processing of internal input and level of cortical activation remains the same as during the waking state. The Vipassana meditation states as elicited by experienced practitioners leads to higher level of cortical activation than during normal waking, while the processing of external inputs is reduced. The serotonine levels during meditation are considered higher than in he normal wake. A: activation; I: input-output gating; M: modulation; Ach:acetylcholine; NA: noradrenaline; NREM: non rapid-eye movement sleep; REM: rapid eye movement sleep.

8.2 Perspectives

Our work brings new types of data and paradigms in the study of mind wandering and meditation. We have for the first time studied the EEG oscillatory dynamic of the mind wandering state and attempted to fill some of the methodological and experimental gaps existing in the study of meditation. However, there is still a long path before being able to fully understand the mechanisms of human consciousness within the realm of cognitive science. Here we will present two perspectives to go further in the study of mind wandering and meditation. A first perspective is the used the altered state provoked by hypnosis induction to better understand characteristics of mind wandering. A second one suggest a new sort of control task for within-subjects comparisons of meditation state effect.

8.2.1 Hypnosis induction as a tool to study mind wandering

We suggest here to study occurrences of mind wandering in the light of another altered state of consciousness: hypnosis. Hypnosis can be seen as a state of focused attention, concentration and inner absorption with relative suspension of peripheral awareness (Faymonville et al., 2006). It is routinely used to reduce stress reaction related to a clinical intervention or even as an adjunct to reduce pain (Faymonville et al., 1995; Butler et al., 2005; Kupers et al., 2005) although its mechanisms are far from being understood.

Interestingly, the litterature mention that subjects report reduction of spontaneous thoughts in the particular state of consciousness induced by hypnosis (Lynn et al., 1996; Oakley, 2008).

This seems to suggest that during hypnosis spontaneous fluctuations of the vigilance level observed in the "normal" waking state (Laufs et al., 2006; Braboszcz and Delorme, 2011) are reduced and that activity of the default mode network (Raichle et al., 2001) is altered.

This network activated when the subject is at rest and deactivated when engaged in a task is primarily made up of posterior cingulate cortex (PCC) and the medial prefrontal cortex (mPFC). Studies coupling both EEG and fMRI found that the activity in different EEG frequency bands is spontaneously fluctuating at rest between a mode dominated by fast frequencies waves and one dominated by slow frequency waves, and that these fluctuations can be correlated to spontaneous fluctuations of the BOLD signal (Laufs et al., 2006; Mantini et al., 2007). Recently, EEG studies have shown that these spontaneous patterns of increased and decreased slow frequencies activity are associated with periods of mind wandering and periods of concentration, respectively

Braboszcz and Delorme (2011); Cahn (2007).

Mind wandering tend to be associated with higher activity within the default network and with executive network recruitment (Christoff et al., 2009; Peterson et al., 2009). More precisely, Stawarczyk et al. (2011a) reported that mind wandering reports compared to on-task reports are associated with higher degree of activity in the MPFC and PCC/precuneus.

During hypnosis a recent study found that activity in the prefrontal cortex is reduced, a result interpreted by the authors as reflecting the suspension of spontaneous cognitive activity (McGeown et al., 2009). The precuneus also seems to play a role in the generation of the internal representations provoked by hypnosis induction (Cojan et al., 2009; Pyka et al., 2011). While previous studies have suggested that hypnosis implies a reduced role of attentional monitoring, with more automatic processes(Egner et al., 2005), Cojan et al. (2009) describe a general increase of activity in area implicated in executive control during hypnosis, and suggest that hypnosis involves a general attentional change corresponding to filtering of external stimulation to allow focalisation on internal representations.

Based on the hypothesis of reduced spontaneous thoughts during hypnosis, we propose to adress the question of wether the emergence of mind wandering is favored or inhibited by the internal representation produced during hypnotic induction and aim at determing the neural correlates this phenomenon.

Classical mind wandering sampling protocol (Gruberger et al., 2011; Christoff et al., 2009; Qin et al., 2011) could be used under the hypnotic state using the Sustained Attention to Response Task (SART) (Robertson et al., 1997), a go/no-go task requiring responses to all stimuli except infrequent targets, coupled with thought probes requiering the subject to rate the "task relatedness" and "stimulus dependency" of their subjective experience prior to the probe (Stawarczyk et al., 2011a).

If compared to the non-hypnotic state, hypnosis produces less mind wandering events, then it would be appropriate to undergo a neuroimaging protocol to understand what are differences in brain functioning between the two states.

Adressing for the first time the effect of hypnosis on spontaneous attentional fluctuations using a combination of high spatial and high temporal precision imaging techniques, this project should make the object of my post-doctoral training and I believe it should shed light both on mechanisms of mind wandering and of hypnosis.

8.2.2 The quest for an ideal control state in meditation study

Define an ideal control state is always challenging, whatever the cognitive function being investigated. In the case of meditation, to avoid any bias, the control task has to be in adequation with characteristics of the practice. For example, in a case where the meditative practice under investigation are done with eyes closed, like in our own experiment, the control task should also be done with eyes closed especially in the case of neuroimaging experiments.

The control task should provoke significant changes in the attentional focus of the subject while, as much as possible, preventing them from entering a meditative-like state. For future studies, we suggest to test using the listenning of an audio book requiering subjects to answer questions at the end of the session to control for the subject's meditative state Indeed, listening to auditory stimuli is likely to give a more external than internal direction to the attention while they have to keep a sustain attention to the audio book in order to answer the subsequent questions and should help subjects not automatically drift towards the meditative state. We also suggest that attending to non-personal material (*i.e.* , not attending to personal thoughts) might help meditators to adopt a less neutral internal attitude towards the fact being told - contrasting with the non-judgemental attitude of meditation.

Although this is purely speculative, we believe this task is worth being tested as providing an efficient control state for the meditative state. Further studies should approve or reject our hypothesis.

8.2.3 Towards a better understanding of the mind

More and more neuroscience is taking a turn towards studying the effects of positive mental state on health and well being. In June 2011, the french Public Health Authority (Haute Autorité de Santé) called for more consideration of non-medicinal therapies in medical prescription [1]. Amongst the obstacles to a large development of these practices is the lack of informations both the praticians and the patient have of the benefits of non-medicinal practices, such as meditation. We believe that a better scientific knowledge of the mechanisms of action of meditation would greatly help the medical professions to recognize and acknowledge the drug-free possibilites meditation offers to help patients suffering of diverse psychological or health problems and to integrate it in the classic "medical toolbox".

Although at a fundamental level our work helps understand better the mechanisms

[1] `http://www.has-sante.fr/portail/jcms/c_1060771/changer-le-regard-sur-les-therapeutiques-non-medicamenteuses`

underlying the natural functioning of the brain, through the study of mind wandering, and of the mechanisms underlying meditation and thus contribute to the research effort aiming at understanding the human mind.

Our wish for the future years is that scientific comprehension of the functionning of the mind will improve and its contributions will spread in the society so that each and everyone could have access to the understanding of the cognitive and biological mechanisms underlying human consciousness and thus make the best use of its possibilities.

Appendix A

Example of an explicitation interview

Example of an explicitation interview

- Subject: MR-170111
- Meditation: non
- Age: 30 ans
- Sexe: M

In the transcription, E is the experimentateur (the interviewer) and S is the subject (the interviewee).

E: Décris moi ce qui vient de se passer là pour toi au moment où tu as tapé sur la table.

S: En fait, je me rend compte que je suis a peu près incapable de rester concentré sur ma respiration, si tu veux y a des trucs qui se bousculent un petit peu dans le sens où en même temps que je compte, les idées montent... j'arrive pas à rester, à ne faire que compter.. c'est du domaine de l'impossible. Donc, euh et puis bon là, je venais de perdre le compte quoi.. ça .. je me rend compte que juste compter, j'y arrive pas.

E: D'accord. A ce moment là au moment où tu as tapé sur la table et où tu t'es redressé .. comment c'était.. qu'est ce qui a fait que tu t'es arrêté ?

S: Bah euh une impression de décrochement total quoi. Les chiffres étaient partis, ça.. ouai l'idée ça euh j'étais plus dans le comptage quoi. Après de là à décrire je..

E: Quand tu dis "les chiffres étaient partis", comment tu sais qu'ils étaient partis ?

S: Parce que je ne les voyais plus. Je visalise quand je compte, c'est... c'est un peu comme, quand je lis dans ma tête, mes lèvres elles bougent quand même et quand je compte dans ma tête, les chiffres ils sont là.

E: D'accord donc là t'étais en train d'essayer de faire la tâche et y a un moment t'as plus vu les chiffres

S: Voilà

E: et donc t'as les idées..

S: C'est le reste des idées qui a pris le dessus sur le comptage.

E: et donc au moment.. donc tu comptais et à un moment t'as plus vu les chiffres et tu dis "le reste des idées à pris le dessus", comment t'as su que les idées ont pris le dessus ?

S: C'était au niveau image... euh ... comment te décrire.. ça donne l'impression, quand je suis comme ça, ça donne l'impression d'un poste de télé qui te fait défiler les images si tu veux. Et les idées sont comme un flot d'images qui passe et à un moment donné entre les idées y a les chiffres qui arrivent et là il y en avait plus. Ca..

E: D'accord. Donc au début t'as les chiffres, tu vois les chiffres et à un moment t'as un flot d'images qui arrive.

S: Oui. En même temps que je compte, voilà, j'ai le compte, j'ai mes images qui défilent. enfin mes idées mais voilà qui sont là. Je suis en train de réfléchir à autre chose en même temps parce que j'arrive pas à me concentrer sur une seule.. un seul comptage et à un moment donné le comptage a été complétement oublié.

E: D'accord. Donc si tu veux, je vais te proposer de le refaire, remets toi comme t'étais. T'étais dans ta position, un peu penché en avant et tu voyais les chiffres, à un moment les chiffres ont été un peu bousculés par le flot des images qui défilaient et donc là t'arrivait plus, t'es plus concentré sur ta respiration.. et euh.. comment, tu peux me décrire les image ? est ce que il y avait des couleurs ? Elles étaient petites, grandes ? Hésite pas à refaire.

S: C'est, c'est des images, j'ai tendance à dire "plein écran". C'est bizarre à dire mais bon, oui c'est je suis dans le, la réflexion autour d'un élevage que je suis en train de faire donc euh je vois mes bestioles, c'est tout.

E: D'accord et donc, t'es en train de compter, tu vois les chiffres, et d'un coup les images en plein écran.

S: Oui

E: ça te prends tout l'espace.. Et comment euh par rapport aux chiffres, est ce que les chiffres prenaient tout l'espace aussi ? Comment est ce qu'ils étaient placés ?

S: Non, à la limite moins oui. Non les chiffres prennent pas toute la place, non clairement pas.

E: Est ce que tu peux me décrire comment sont les chiffres ?

S: euh.. [ferme les yeux] je les vois forcément plein écran là

E: Hésite pas à refaire

S: Je peux reprendre le..

E: Oui, pour te remettre dans le bain . . .

S: Oui, c'est du floutage. Ca se superpose et ça se floute c'est vraiment, c'est euh.. Voilà c'est ça . Donc le chiffre est plus ou moins, prend la place qu'il y a dispo, mais les idées se calent par dessus, ça floute voilà. En fait ça, enfin même pour compter si on par de 1 effectivement y a le 1 mais y a le 2 qui se superpose par dessus avec une 3ème image ça, c'est vraiment de la superposition de trucs avec euh un voile de fond qui est le comptage.

E: D'accord, donc là devant toi tu as des chiffres qui viennent se superposer et les images

S: et les images encore qui viennent par dessus

E.. qui superposent par dessus et donc tu continues à compter et au bout d'un moment t'as vu ton élevage.. je sais pas quelle bête

S: ce sont des criquets

E: des criquets, qui se sont superposé. Et à ce moment là, quand tu compte et que tu vois les images, ta respiration tu la sens comment ? Tu la sens à un endroit particulier ? Comment tu sais que tu respires et que tu comptes tes respirations ?

S: j'en sais rien.. je compte à chaque inspiration donc ça, c'est au moment où je reprend de l'air, enfin c'est au moment où j'ai plus d'air que je sais qu'il faut que je compte le suivant. Ca..

E: D'accord, donc euh au moment où tu euhh comment tu sais que tu reprends de l'air ?

S: j'en sais rien... ohlàlà

E: c'est par, au niveau des sensations, c'est ton ventre qui se gonfle, ton nez ?

S: Non, c'est les poumons qui se gonflent. C'est vraiment le haut de la cage thoracique qui.. qui prend. Je respire pas avec le ventre. /................./ Si je me concentre sur ma respiration, j'oublie de compter.

E: D'accord

S: Disons que là j'essayais de compter en même temps que j'essayais de comprendre le moment de l'inspiration, voir le moment de .. enfin et du coup j'en oublie de compter au moment où j'inspire, ça..

E: D'accord. Mais quand tu fais en comptant en même temps..

S: Je réfléchis pas à la respiration, je sais que quand j'inspire c'est le moment de changer de chiffre et finalement je me rends même plus compte que c'est à l'inspiration que je compte.

E: D'accord, et tu m'as dit que ça se passait quand même dans le haut de la cage thoracique.

S: Oui, je respire que par le.. dans un cas où je me suis concentré effectivement je ne respire que par le haut de la cage, et par le nez.

E: Donc si on reprend, t'es concentré à compter tes respirations, et donc tu voyais les chiffres qui apparaissaient devant.

S: Oui

E: Ta respiration, tu la sentais pas vraiment, mais c'était plutôt au niveau de la cage thoracique ou bien t'avais aucune sensation ?

S: Non, y a que la sensation d'inspiration que j'ai, c'est tout. Enfin oui, je le sens gonflé mais pas... c'est pas sur ça que je suis concentré, je l'oublierai presque.

E: d'accord, mais si par exemple moi je devais la ressentir, comme tu la ressens la sensation d'inspiration,, qu'est ce que je devrais ressentir ?

S: /...../ je sais pas comment décrire, à part la sensation de tension au niveau de la cage thoracique... la cage qui est repoussée, c'est vraiment le, la sensation que j'en ai quand je suis là c'est le blocage, enfin le gros du truc que je peux sentir c'est le moment où j'ai rempli complètement, où je suis à bloc. C'est là que je sais vraiment que le comptage doit continuer. C'est même pas à l'inspiration, c'est vraiment une fois que tout est bloqué, quand j'ai rempli au max.

E: D'accord. Donc t'as commencé à compter, à cette fois que t'as eu cette sensation de rempli à bloc tu changes de chiffres et euh donc tu comptes et au bout d'un moment y a des images qui viennent se surperposer devant les chiffres. Et à ce moment là euh.. qu'est ce qu'elle devient la sensation de blocage ?

S: elle est oubliée puisque j'expire et que c'est la libération

E: d'accord, donc au moment où les images, les pensées viennent se superposer aux chiffres, c'est le moment où t'expire ?

S: oui, oui oui

E: et au moment où t'as expiré la suite de la respiration tu..

S: Je ne m'en rends pas vraiment compte jusqu'à ce que je commence à sentir le, le remplissement. J'ai pas la sensation de gérer vraiment la respiration. /...../ Je me concentre trop sur la respiration.. disons que y a pas d'effort au vidage et du coup c'est là que j'ai plus le temps de réfléchir. Le tuc c'est que j'ai l'impression de m'obliger à inspirer et du coup je suis obligé de me concentrer sur cette inspiration, que l'expiration ne me demande pas d'efforts, elle se fait toute seule. Et du coup à ce moment là je suis entre guillemets libre de laisser courir mes pensées.

E: D'accord et au moment où t'as tapé sur la table, juste avant ça donc t'avais eu les pensées qui étaient arrivées et euh ton attention sur la respiration, ta respiration tu la sentais toujours ?

S: Non. C'est pour ça que je me suis relevé, enfin que j'ai tout arrêté c'est que je n'étais même plus concentré sur la respiration. Ca.. je vais pas dire que j'ai eu la sensation d'étouffement, on en est pas là mais j'ai pas inspiré aussi fort que les fois précédentes parce que je n'étais plus autant concentré sur la respiration. Ca, voilà.

E: Ok. Donc si je reprends un petit peu pour remettre le scénario au clair. Donc t'es en train de compter donc à chaque inspi tu sens une sensation de blocage ca te fait compter le chiffre suivant..

S: Oui.

E: Tu voyais les chiffres devant toi qui se superposent, le 1, le 2 et au bout d'un moment les pensées sous forme d'images vraiment grand écran qui sont venues et à partir de ce moment là t´ as l'impression que c'est moins..

S: Dans un premier temps, j'arrive à garder le fil, euuh entre deux pensées qui viennent interrompre le processus. Je suis pas en changement de c hiffre, je suis toujours dans la même respiration donc ca va. Et à un moment donné, le flot de pensées est plus important que le comptage et la respiration et du coup je perds le ca euh, je perds le fil.

E: D'accord. Et quand tu dis le flot de pensées était plus important que la respiration, comment tu sais qu'il était plus important ?

S: C'est l'attention qui se déplace, disons que le .... la tâche principale entre guillemets est carrément oubliée au profit des idées qui arrivent quoi euuh là où c'était des bribes d'informations qui sont entrecoupées entre deux respirations là c'est carrément, je suis parti sur mon truc et j'ai oublié le reste quoi.

E: D'accord. Donc au bout d'un moment où tu comptes, tu voyais les chiffres, tu voyais des images qui venaient s'intercaler entre les chiffres et au bout d'un moment les images prennent le dessus

S: ouai, c'est ca, c'est vraiment le..

E: Et est ce que tu peux me décrire le moment où les images prennent le dessus ? Est ce que ca s'accompagne, est ce que t'entends une voix, est ce que t'entends des sons.. ?

S: Non, non c'est non y a pas de sons, j'arrive pas à me concentrer assez pour décrocher au niveau auditif, donc ca c'est pas possible. Quand je compte si tu veux, je change pas d'espace, l'environnement est toujours là, donc non au niveau son y a rien qui se déclenche. Par contre ca va être au niveau visuel où je dirais que les idées s'animent.. c'est plus vraiment des images ca va être du, c'est du mouvement qui s'installe. Au lieu d'avoir des images qui se superposent effectivement, on peut passer sur une idée de film qui va défiler.

E: Donc t'étais en train de compter, qu début tu sentais bien ta sensation d'inspi, la sensantion de blocage, de poumons remplis, tu changes de chiffre , y a des pensées qui s'intercalent quand même à chaque fois entre chaque chiffre mais tu restes sur la tâche de comptage et au bout d'un moment, les pensées prennent de plus en plus de place et elles commencent à s'animer.

S: Oui.

E: Donc le contenu euh, comment ca se passe quand ca s'anime, est ce que y a des couleurs ? est ce que toi t'as ta voix intérieure qui te racontes un peu ce qui se passe autour des images ?

S: Non, non non. Enfin au niveau oui couleur, oui oui. Je pense en couleurs. Mais sinon non, comme je dis y pas de sons, y a pas de... au niveau inconscient y pas de dictée, y a pas de tout ca. Par contre ouai, c'est de l'animation, c'est ... ca ca me fait penser quand ca.. quand il y a l'aquarium sur le côté, qu'on regarde la télévision et que d'un seul coup l'aquarium est plus intéressant que la télévision. Voilà, c'est un truc qui m'arrive souvent, c'est je regarde la télé et au bout d'un moment finalement l'aquarium à plus d'intérêt que la télévision. Et c'est vraiment ca le truc. L'intérêt se déporte.

E: D'accord. Et ces images qui arrivent au moment où t'es en train de compter les images qui commencent à s'animer et à prendre le dessus, elles ont une direction particulière, elles arrivent d'un endroit particulier ?

S: Oui. Elles arrivent de la droite. Ca peut sembler très con mais ca déphase c'est vraiment une sensation de diapo qui arrive de la droite, à l'ancienne. Ca.. voilà.

E: D'accord. Donc t'es en train de compter, tu vois les chiffres, eux ils apparaissent devant toi ?

S: oui, les chiffres se se comment dire. Les chiffres ont, c'est vraiment une sensation de flou qui se superposent les uns aux autres.

E; D'accord. Donc flous et ils se superposent les uns aux autres. Et de temps en temps t'as des pensées qui elles aussi viennent se superposer ?

S: Qui viennent se superposer en transparence effectivement.

E: en transparence, et au bout d'un moment c'est plus les pensées qui viennent se superposer en transparence, c'est comme une diapo qui arrive de la droite.

S: Oui.

E: Et qui va prendre la place...

S: Oui qui prend la place et ca finit par s'animer pour avoir euh, oui

E: D'accord. Et tu m'as dit ton attention va se déplacer.

S: Oui

E: Comment.. comment tu sais que ton attention se déplace ? Comment ca se passe ?

S: A la limite c'est même l'inverse qui se passe. C'est pas tellement le, la diapo qui vient se placer par dessus mais plus l'impression d'avoir la, de passer la tête à autre chose. De tourner la tête vers autre chose. Ca ouai, ouai ouai c'est.. c'est même pas les choses qui viennent passer par dessus à la limite c'est vraiment.. quand je perds le comptage c'est l'impression si tu veux que les chiffres sont là en train de défiler et que je pars pour aller voir autre chose.

E: D'accord. Donc les chiffres défilent là et toi tu pars, parce que tu sens que t'as un mouvement de déplacement...

S: Oui oui ca c'est ca, la sensation de regarder ailleurs.

E: D'accord. Et euh cet ailleurs, y a une direction particulière ?

S: Oui comme je te disais les images viennent de la droite, et ca serait la sensation d'aller vers la droite.

E: D'accord. Donc je reprends. T'es en train de compter, à chaque inspi tu vois les chiffres un peu flous qui apparaissent et qui se superposent en transparence devant toi, avec de temps en temps d'autres images qui viennent se superposer, des pensées

S: oui

E: et au bout d'un certain temps, les pensées deviennent plus importantes et arrivent de la droite comme des diapos, elles sont animées et à ce moment là t'as la sensation d'un déplacement.. tu me dis tourner la tête, tourner ton attention vers la droite et là, c'est à ce moment là que t'oublie la tâche de compter ?

S: Oui, les chiffres sont plus là.

E: D'accord. Et quand tu me dis 'ca se décale vers la droite, mon attention se décale vers la droite', tu peux me décrire ce qui se passe, comment est ce que tu sais que l'attention se décale, est ce que tu sens tes yeux bouger, est ce que t'as des sensations particulières ?

S: Uhum, oui j'aurai presque les yeux qui bougent. Oui oui, ah oui oui. C'est.. j'y ai pas réfléchi mais c'est vrai quand [......] En fait c'est pour compter il faut que j'ai le.. la sensation que j'ai c'est que je dois avoir le regard devant. Et dès que j'ai les yeux qui bougent, je suis à autre chose. Là j'étais en position, j'avais la tête baissée. Dès que j'ai le regard fixe, les yeux fixes devant je compte, dès que je relache, j'arrête de compter. Là typiquement j'ai eu la sensation d'avoir les yeux qui ont légèrement relevés et automatiquement, je perds le compte.

E: D'accord. Et donc tu comptes avec les yeux devant et au moment où euh, tu vois tes chiffres devant toujours et à un moment donc t'as ces images qui arrivent de la droite et là tes yeux vont se déplacer, c'est bien ca ?

S: Oui. En fait quel que soit le mouvement des yeux, là typiquement c'était vers le haut, je change de euuh entre guillemets de pensée, je perds l'attention sur mon décompte et je passe à autre chose. C'est l'impression d'avoir le compteur devant et au bout d'un moment le compteur devant et au bout d'un moment je perds la fixation du compteur et je finis par regarder quelque chose qui est autour.. mes pensées sont autour.

E: Les pensées sont autour du compteur..

S: Oui

E: Donc si on revient, au moment où, la fois précédente tu me disais c'est des images qui arrivent par la droite. Au moment où tu les vois arriver, est ce que tu peux me décrire comment elles sont ces images ? Comment est ce qu'elles arrivent, si elles sont déjà nettes, floues ? Si elles sont déjà en couleur ?

S: [..] C'est net. De là à dire en couleur, je saurais pas dire, j'ai du mal à.. [...] non c'est pas en couleur.

E: D'accord. Donc au début c'est pas en couleur, mais après tu vas les voir en couleur ?

S: Oui, oui. Plus je suis, disons que ca.. si je reste sur mon décompte.. Non, les couleurs sont là quand je pers le fil. Une fois que je suis sur la.. plus sur mon idée que sur le comptage là j'aurai de la couleur, mais avant non.

E: D'accord. Donc au début quand tu comptes avec les yeux fixés devant et que tu vois les chiffres qui se superposent en flou, les images aussi, les images sont en gris, en noir et blanc ?

S: Oui.

E: et à un moment tu vas en voir arriver par la droite qui sont en noir et blanc, qui vont se superposer et elles vont prendre de la couleur quand elles vont prendre de l'importance.

S: oui

E: et le mouvement il y est déjà quand elles arrivent ?

S: Oui. C'est le mouvement qui...

E: L'animation de l'image, quand elle arrive ?

S: elle ne se fait que quand j'ai les yeux fixés dessus.

E; D'accord. Et tu m'as dit aussi quand tu comptes, t'as l'impression d'avoir le compteur devant avec les yeux fixés dessus et que les idées sont autour ?

S: Oui.

E: et donc l'image qui arrive par la droite, est ce que tu pourrais me décrire si elle arrive, elle sort de rien ou si elle était déjà autour ?

S: Ca c'est difficile à dire, j'ai pas de sensation particulière [....] je réfléchis trop là...

E: D'accord. Si tu veux je vais reprendre moi les éléments que j'ai et tu me dis si j'ai oublié quelque chose, si tu veux préciser. Donc je t´ ai demandé de compter tes respirations de 1 à 10 en boucle, t'as pris une position un peu comme ca, la tête dans les mains et t'as commencer à compter. Donc à ce moment là t'avais les yeux qui étaient fixés droit devant toi, tu sentais ta cage thoracique qui se gonflait et quand elle était à bloc tu savais qu'il fallait changer de chiffre, donc tu comptais 1,2.. comme ca. Mais toutefois toujours entre les chiffres t'avais des pensées qui venaient aussi se superposer. Donc les chiffres tu les voyais devant toi en flou en transparence et y avait aussi des pensées qui étaient sans couleur, qui venaient se superposer aux chiffres en transparence. Et au bout d'un moment y a eu une image qui est arrivée par la droite, qui au dápart n'était pas animée et en noir et blanc, qui est venue se mettre devant, qui a rempli l'espace. Qui était plus grande que les autres ?

S: Plus grand non. Disons que j'ai l'impression d'avoir toujours le visu en vision plein écran.

E: D'accord. Donc l'image est venue plein écran et elle a commencé à s'animer, à prendre des couleurs

S: Oui

E: et à ce moment là tu me dis, tu faisais plus du tout attention à la tâche, t'étais concentré sur l'image et euh, je voudrais juste qu'on essait de revenir peut être au moment où l'image commence à prendre des couleurs, comment était ta sensation de respiration à ce moment là ?

S: Relachée. Justement c'est ca qui m'a fait prendre conscience que je n'étais plus à ma tâche, c'est que je ne respirais plus à fond.

E: D'accord. Et est ce que tu pourrais me décrire si les couleurs étaient là depuis longtemps ou si c'est arrivé en même temps ?

S: Non c'était avant. Longtemps je pourrai pas dire, mais j'ai pris conscience que j'avais arrêté de compter bien après la couleur et l'animation.

E: Ok. Et au moment où tu as tapé sur la table, donc, tu voyais, t'étais dans l'image, t'as tapé sur la table, comment tu as pris la décision de taper sur la table ? De donner le signal ?

S: Ca c'est terrible comme question, j'en sais rien. Disons qu'au moment où je sens que je ne suis plus en train de respirer profondément, j'ai ouvert les yeux.Je me suis rendu compte que j'étais plus en train de faire ce que je devais faire. Du coup j'ai ouvert les yeux, et j'ai tapé la table qu'après avoir bien compris que, je vais pas dire que j'étais revenu, mais presque.

E: D'accord. D'accord donc au moment où l'image est arrivée, elle était en plein écran, elle était animée, elle avait des couleurs, au bout d'un certain temps, tu t'es apercu que tu respirais plus aussi à fond qu'avant, que ta respiration était plus légère et ca ca t'as fait ouvrir les yeux, et c'est là que tu t'es dis "je suis plus en train de faire la tâche".

S: Oui.

E: D'accord. Est ce que tu vois des choses à ajouter ?

S: Non.

Appendix B

List of publications and communications

Publications

International peer-reviewed journals

- **C. Braboszcz** and A. Delorme. Lost in thoughts: neural markers of low alertness during mind wandering. *Neuroimage*, 54(4):3040–7, 2011.

- Grandchamp R., **Braboszcz C.**, Makeig S., Delorme A. "Stability of ICA decomposition across within-subject EEG datasets" in *Engineering in Medicine and Biology Society, 2012* Proceedings of 34th Annual International Conference of the IEEE, 2012 *in press*.

Book chapter

- **C. Braboszcz**, S. Hahusseau, and A. Delorme. Meditation and neuroscience: from basic research to clinical practice. *In Roland A. Carlstedt, editor, Handbook of Integra- tive Clinical Psychology, Psychiatry, and Behavioral Medicine: Perspectives, Practices, and Research*. Springer Publishing Co Inc, 2010

Communication in international conferences

- **Braboszcz, C.**, Cahn,R., Balakrishnan, B., Grandchamp, R. and Delorme, A. - Is med- itation improving attention ? A study on 82 Isha meditation practitioner following a 3 months retreat, poster presentation , *ECVP 2011*, Toulouse, France

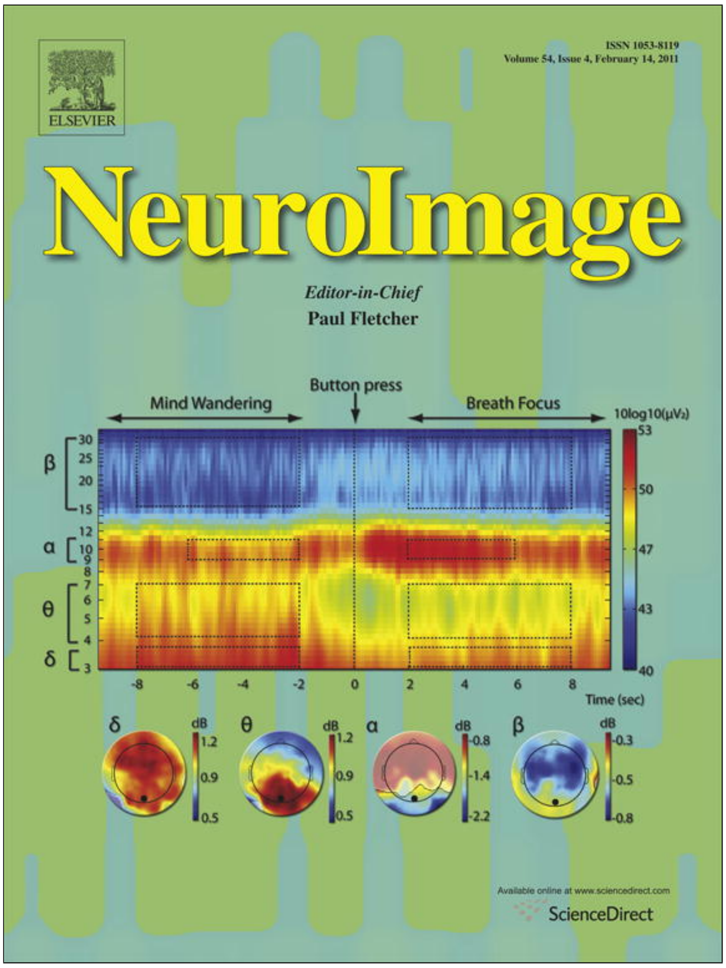
- Grandchamp, R., **Braboszcz, C.**, Hupe, J.M., and Delorme, A. - Pupil dilatation during mind wandering, poster presentation , *ECVP 2011*, Toulouse, France

- Karalis, N., Karanasiou, I.S., **Braboszcz, C.**, Uzunoglu, N.K. - Effects of Himalayan Tradition meditation during a SSVEP study, *Society of Applied Neurosciences 2011*, Thessalonique, Greece

- **Braboszcz, C.**, Fernandez, M., Cahn, R., Delorme, A. - Neurophysiological correlates of meditation in the Himalayan Yoga tradition, *International Conference on Yoga for Health and Social Transformation 2011*, Patanjali Yogpeeth, Haridwar, India
- **Braboszcz, C.**. and Delorme, A. - Lost in Toughts: Neural markers of low alertness level during mind-wandering, poster presentation , *ICCNS 2009*, Boston University, Boston

Appendix C

Article: Lost in thoughts: neural markers of low alertness during mind wandering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Lost in thoughts: Neural markers of low alertness during mind wandering

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ABSTRACT

During concentration tasks, spontaneous attention shifts occurs towards self-centered matters. Little is known about the brain oscillatory activity underlying these mental phenomena. We recorded 128-channels electroencephalographic activity from 12 subjects performing a breath-counting task. Subjects were instructed to press a button whenever, based on their introspective experience, they realized their attention had drifted away from the task. Theta (4–7 Hz) and delta (2–3.5 Hz) EEG activity increased during mind wandering whereas alpha (9–11 Hz) and beta (15–30 Hz) decreased. A passive auditory oddball protocol was presented to the subjects to test brain-evoked responses to perceptual stimuli during mind wandering. Mismatch negativity evoked at 100 ms after oddball stimuli onset decreased during mind wandering whereas the brain-evoked responses at 200 ms after stimuli onset increased. Spectral analyses and evoked related potential results suggest decreased alertness and sensory processing during mind wandering. To our knowledge, our experiment is one of the first neuro-imaging studies that relies purely on subjects' introspective judgment, and shows that such judgment may be used to contrast different brain activity patterns.

Introduction

While reading books, most people have had the experience of finding their attention drifts towards self-centered matters. After some time (ranging from seconds to minutes), the readers realize they are mind wandering and bring their attention back to their reading. Mind wandering episodes thus correspond to the emergence of task-unrelated thoughts and affects that are attracting the attention away from the task at hand (Smallwood and Schooler, 2006; Mason et al., 2007). Not surprisingly, mind wandering episodes occur in our everyday life quite often—for instance, as soon as we perform a task and start realizing we are thinking about something else while doing it. One may think that avoiding these attention shifts is only a matter of concentration and willingness to carry out a mental task. Yet, after weeks, months, or years of training in tasks involving sustained concentration–such as focused meditation practice–subjects realize that these events seem to just happen, despite purposefully trying to avoid them—see Braboszcz et al. (2010) for a review of mind wandering during meditation practice.

The experience of mind wandering thus highlights the existence of moment to moment subjectively-attested changes of attentional focus from a task to non-task related thoughts and we believe that these changes would most likely be associated with different brain activity. Although it is a common phenomenon, and although its implication for consciousness research and the study of attentional processes is critical, the brain dynamics associated with mind wandering have not yet been studied directly.

Mind wandering has been associated with lower level of alertness and vigilance (Oken et al., 2006), a mental state with limited external information processing where attention is decoupled from the environment (Smallwood and Schooler, 2006). Supporting this hypothesis, human subjects exhibited decreased performance in rare-target oddball detection tasks during mind wandering (Giambra, 1995). In addition, the amplitude of the P300 event-related potential component was reduced during mind wandering, suggesting a decrease in attentional resources directed towards stimulus processing (Smallwood et al., 2008).

Although the brain dynamics associated with mind wandering have not been studied, a number of studies have investigated the brain dynamics associated with the resting state—an awake neutral state that is not associated with any specific cognitive task and that is prone to mind wandering (Gusnard and Raichle, 2001; Mazoyer et al., 2001). Studies coupling both EEG and fMRI found that the activity in different EEG frequency bands is spontaneously fluctuating at rest and can be correlated to spontaneous fluctuations of the BOLD signal (Laufs et al., 2006; Mantini et al., 2007). These fluctuations seem to underlie two distinct modes of cerebral activity: a mode dominated by

Abbreviations: MW, mind-wandering; BF, breath focus; Odd, oddball stimulus; Std, standard stimulus; ERSP, event related spectrum perturbation.

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fast frequency waves (12–30 Hz, beta) that may index higher degrees of task-related attention (Ray and Cole, 1985; Laufs et al., 2006), and a mode dominated by slow 3–7 Hz theta waves oscillations that has been linked to decreased sustained task-related attention and diverse stages of transition from wake to sleep (Loomis et al., 1937; Makeig and Inlow, 1993; Klimesch, 1999; Smit et al., 2005). Based on these results, we hypothesized that task-unrelated attentional drifts–i.e. mind wandering–would be associated with decreased vigilance and increased delta and theta power.

It has also been shown that brain evoked responses to external stimuli change with the degree of vigilance or sleep stage. For example, the negative brain evoked response to the sensory detection of a sudden change in the flux of auditory perception called mismatch negativity (Naatanen et al., 2007) is reduced during the early sleep stages and drowsiness (Lang et al., 1995; Winter et al., 1995). Since the mind wandering state should be associated with decreased vigilance, we expected to observe a decrease in the mismatch negativity amplitude in the mind-wandering state compared to the breath focus state.

We designed an experiment allowing subjects to experience mind wandering in conditions we believe to be as close as possible to the way they are experiencing it in their daily life. We chose a simple concentration task–a silent breath counting task–that only requires weak cognitive involvement from the subject, a characteristic known to favor the induction of mind wandering (Giambra, 1995; Cheyne et al., 2006). Simultaneously we presented frequent and rare pure-frequency auditory stimuli that subjects were instructed to ignore, and we used these stimuli to assess the evoked electrophysiological activity during the mind wandering and breath concentration states.

Materials and methods

Participants

Sixteen volunteers from the laboratory staff and local universities (8 females and 8 males; age 19–36 years old, mean: 27 and standard deviation 5) gave written consent to participate to the experiment. Participants stated that they were not taking any substances or medications that could potentially affect their concentration nor having histories of major psychological disorders or any auditory deficiencies. Before starting the experiment, all participants read the instructions and had the possibility to ask questions about the experiment before giving written consent to participate in the experiment. As detailed below, 4 of the 16 participants had to be excluded because they did not report enough mind wandering episodes.

Procedure

Participants sat in a dark room. We asked them to keep their eyes closed during the recording session. Participants were instructed to count each of their breath cycles (inhale/exhale) from 1 to 10. As subjects often lack immediate awareness of their mind wandering episodes (MWE), we could not ask them to signal MWE occurrence at the moment their attention was drifting away from the task. Instead, we asked them to indicate whenever they realized their attention had drifted, that is whenever they gained meta-consciousness (Schooler, 2002) of their mind wandering episodes. We asked subjects to hold a button in their right hand and press it whenever they became aware of having lost track of their breath count. The following instructions were given to subjects to define what was meant by losing track of the count: “you stopped counting,” “you counted over 10 breaths” or “you had to reflect intensively to figure out what was the next count.” Once they pressed the button, participants were instructed to bring their focus back to their breath and start counting again from one. We read task directions to participants and made sure they understood them.

The experiment lasted about 1 h and 10 min, split into three blocks of 20 min separated by 5 min of rest. At the end of each block, we asked subjects to evaluate their alertness level during the past session (“Did you feel like falling asleep?”), their eye movement activity (“Did you open your eyes —if yes can you estimate how many times”), and their subjective experience when reporting mind-wandering episodes (“Did you press the button? If yes, what was your subjective experience?”). None of the participants reported systematically opening their eyes and none of the participants reported falling asleep. However, 6 of the 12 selected participants reported some level of drowsiness at one time or another during the 1-h experiment (see Discussion).

Auditory stimuli

While performing the breath counting task, subjects were also presented with a passive auditory oddball protocol that they were instructed to ignore. The auditory oddball protocol was composed of pure sounds of 500 Hz for the standard stimuli (80% of the stimuli) and 1000 Hz for the oddball (20% of the stimuli). Each sound lasted 100 ms with 10 ms linear amplitude rising and falling times. Inter-stimulus intervals randomly varied between 750 and 1250 ms. Oddball stimuli presentation was pseudo-random to ensure there were never two oddball stimuli presented successively. Auditory stimuli were calibrated at 72 dB and played through a loudspeaker located at 1.20 m in front and 45 degrees on the right of the subject.

Recording

We recorded data using a 128-channel Waveguard™ cap (Advanced Neuro Technology Company—ANT) out of which we used 124-channels—electrodes AFZ, PO6, TP7, and PO5 were damaged and left out. We plugged the Waveguard™ cap into two synchronized 64-channel EEG amplifiers also from the ANT Company. We kept most electrode impedances below 5 KOhm although about 10% of the electrodes still had higher impedance at the end of preparation–all impedances were kept below 20 Kohm as recommended in ANT ASA 4.0 software user's guide–ANT recommendation is higher than the standard 5 Kohm because of the high impedance of its amplifier. We used M1 mastoid electrode as reference and sampled the data at 1024 Hz. We also recorded EKG by placing two bipolar electrodes on each side of the subject's torso.

Artifacts correction

We first removed bad electrodes—from 2 to 17 bad electrodes per subject. We then manually pruned the continuous data from non-stereotyped, unique artifacts such as paroxysmal muscles activity–high frequency activities with large amplitude over all electrodes–as well as electrical artifacts resulting from poor electrode contacts–short-lasting aberrant oscillatory activity localized at a few electrode sites. We then used Infomax Independent Component Analysis (Infomax ICA) on the pruned data to reject artifacts. For each subject, we visually identified and rejected one to five well-characterized ICA components for eye blink, lateral eye movements, and temporal muscle noise (Delorme et al., 2007a). We used visual inspection of component scalp maps, power spectrum and raw activity to select and reject these artifactual ICA components.

Data processing

Data processing was performed under Matlab 7.0 (The Mathworks, Inc.) using the EEGLAB 7 toolbox (Delorme and Makeig, 2004). We first downsampled the EEG data from 1024 Hz to 256 Hz and performed high-pass filtering at 1 Hz using a non-linear elliptic filter. In addition, we applied an elliptic non-linear notch filter between 45 and 55 Hz. For each subject, we then segmented the EEG data into 20-s data epochs centered on subjects' button presses. We considered that participants were mind wandering during the 10-s period that preceded the button press and we considered that participants were concentrating on their breath during the 10-s period that followed the button press (Christoff et al., 2009). Four subjects did not have enough clean data epochs to be considered for further analysis—the four subjects had six, five, five and one clean epochs respectively. All the selected subjects had between 13 and 52 of such 20-s clean EEG data epochs (mean of 30 per subject; standard deviation of 14). This ensured that, for each subject, there would be at least 20–30 auditory stimuli in each condition to compute ERPs (Kappenman and Luck, 2010)—see ERP analysis below. The total number of analyzed mind wandering events across all subjects was 358.

For each of the two conditions, mind wandering and breath focus, we also extracted data epochs from 1 s before to 2 s after the presentation of auditory stimuli. So that auditory stimuli do not occur too close to a button press, we removed all 3-s data epochs containing a button press—thus button presses were at least 1 s prior to the stimulus or at least 2 s after the stimulus. This procedure ensured that the brain activity related to the button press does not contaminate our analysis. In addition, we processed brain activity from electrodes (Oz, Fz) that were not over pre-motor and motor regions limiting potential contamination of button press brain-related activity. We thus obtained four groups of data epochs—oddball and standard stimuli defined over two conditions, mind wandering and breath focus. We computed mean event related potential (ERP) using a –300 to 0 ms baseline and we performed ERP visualization after applying a 30 Hz linear low pass filter—note that we used the non-filtered data for computing statistics. We counted a total of 4326 standard stimuli (mean of 180 per subject; standard deviation of 101) and 1040 oddball stimuli (mean of 43 per subject; standard deviation of 23).

EEG time-frequency analysis

We applied Morlet wavelet decomposition (Goupillaud et al., 1984) to both the 20-s long data epochs time-locked to button presses and the short 3-s data epoch time-locked to auditory stimuli. We used 200 linearly-spaced time points and a series of 100 log-spaced frequencies ranging from 1 Hz to 100 Hz, with 1.5 cycle at the lowest frequency increasing linearly and capping at eight cycles at 30 Hz. For long 20-s epochs, we visualized absolute log power — 10*log10 (X), X being absolute power at a given time-frequency point. For short 3-s epochs time-locked to auditory stimuli presentation, we also removed baseline spectral activity by subtracting the pre-stimulus average baseline log-power at each frequency in order to visualize power changes in dB unit (Delorme and Makeig, 2004).

Statistics

Statistical tests were performed on ERPs, time-frequency maps and topographic maps using two-tailed paired parametric student t-test ($df = 11$). Since most representation involves hundreds of tests, correction for multiple comparisons was performed using the cluster method as developed by Maris and Oostenveld (2007). This method first measures the extent of 1-D (length) or 2-D (surface) of significance regions (uncorrected) and then tests if the extent of these regions is significant using a Monte-Carlo approach. For channel topographies, we set the number of channel neighbors to 4.5 before running Maris and Oostenveld (2007) Matlab function. We also used FDR (False Discovery Rate) (Benjamini and Yekutieli, 2001) to correct for multiple comparisons and obtained similar results compared to the cluster method.

Results

EEG activity time-locked to meta-consciousness events

The time frequency analysis of EEG data time-locked to meta-consciousness event–button press shows a significant influence of the subject's attentional state at all frequency bands from 2 to 25 Hz

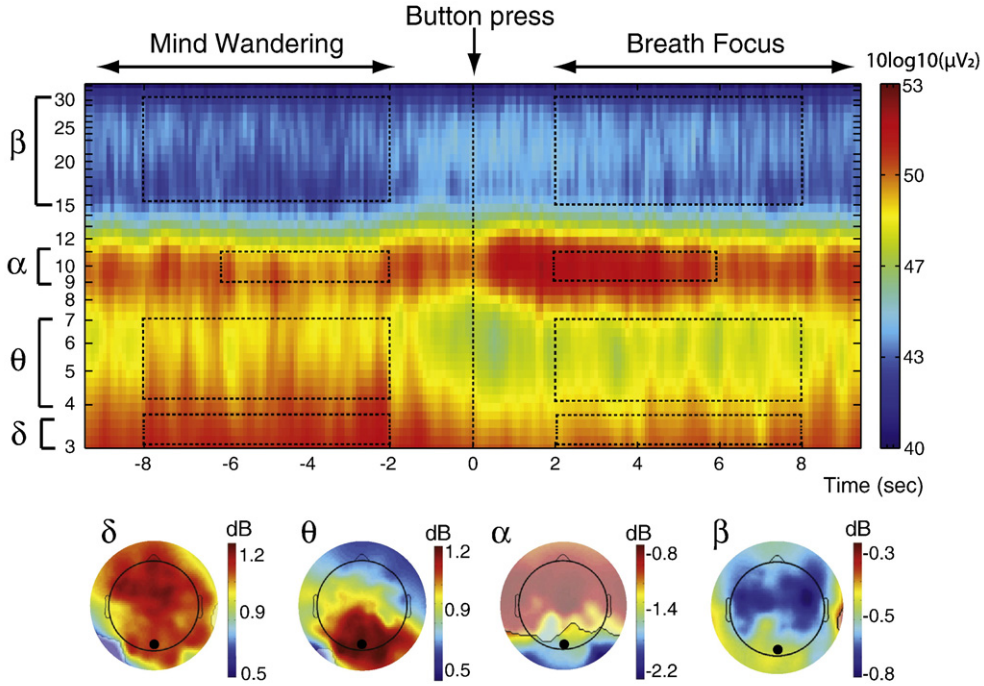

Fig. 1. Time frequency decomposition of transition from mind wandering to breath focus at electrode site Oz. Mind wandering was defined as the period preceding the meta-conscious event (button press) and breath focus was defined as the period following the meta-conscious event. Topographic maps of power difference are shown for the 2–3.5 Hz (δ), 4–7 Hz (θ), 15–30 Hz (β) frequency bands from −8 to −2 s before and from 2 to 8 s after the button press. Topographic map of differential power is shown for the 9–11 Hz (α) frequency band from −6 to −2 s before and 2 to 6 s after the button press (unlike other frequencies bands, the difference of power in the alpha band between mind wandering and breath focus was not significant for a larger time interval). Areas of statistical significance (p<0.05) are highlighted on the topographic maps (shaded areas represent non-significant regions for the alpha band topographic map; all electrodes are significant for other frequency bands). The black dot represents the position of electrode Oz.

(Fig. 1). The most pronounced state-associated change on the EEG spectral activity occurs in the theta band (4–7 Hz) where absolute spectral power is significantly higher in the mind wandering state compared to the breath focus state. This effect is observed at all electrode sites and is larger over occipital and parieto-central regions. Absolute power in the delta band (2–3.5 Hz) showed the same trend although the largest power difference was now observed over the fronto-central region. By contrast occipital alpha (9–11 Hz) and fronto-lateral beta (15–30 Hz) power was significantly lower in the mind wandering state compared to the breath focus state.

During the transition associated with the meta-consciousness (MC) event, the alpha frequency band in Fig. 1 is not only affected in terms of amplitude but also in terms of peak frequency. The peak frequency appears to increase by about 1 Hz after the meta-conscious event for a period of about 2 s. To test if this observation was significant across subjects, we defined three time windows, W1 from −6 to −4 s before the MC event; W2 from 0 to 2 s after the MC event; W3 from 6 to 8 s after the MC event. For each subject and for each time window, we then manually assessed the alpha peak frequency by taking the frequency of maximum power between 8 and 12 Hz on the power spectrum—the power spectrum was computed by averaging log-power values of Fig. 1 over the windows of interest W1, W2 and W3. Note that the alpha peak frequency could not be found for one of the 12 subjects so we computed statistics using 11 subjects only. Bootstrap statistics revealed significant difference between the central W2 window and the flanking W1 and W3 windows (W1 versus W2, $p<0.0005$, $df=10$; W3 versus W2, $p<0.002$, $df=10$) but not between W1 and W3. Supplementary Fig. 1 is a movie showing the dynamical change in the power spectrum where the alpha amplitude changes and peak frequency shifts are made clearly visible.

Stimulus evoked activity during mind wandering and breath focus

We first tested if the attentional state affected grand average ERPs of the auditory stimuli in the passive oddball paradigm. We observed that the ERP positive component at about 200 ms after stimulus presentation (P2) is significantly higher over fronto-central sites from 180 to 280 ms during mind wandering than during breath focus for both standard and oddball stimuli (Fig. 2). We did not observe any

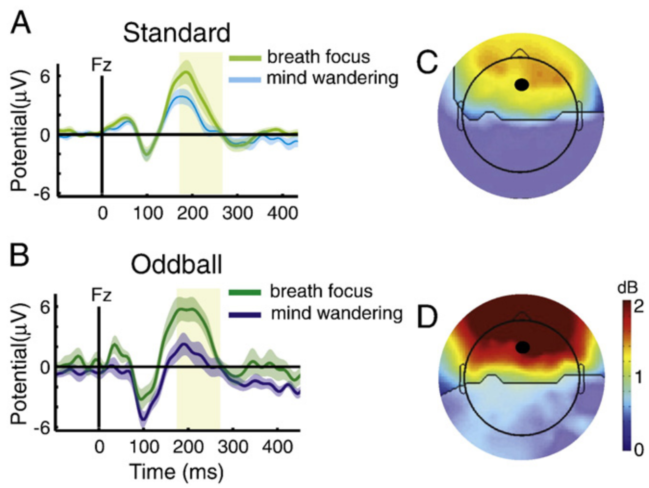

Fig. 2. Effect of the attentional state on the grand-average ERP for oddball and standard stimuli. (A, B) ERP at electrode site Fz for the mind wandering and the breath focus state for standard (A) and oddball (B) stimuli. The shaded area surrounding each curve represents the standard error of the mean. (C, D) Topographical maps of the average ERP difference between mind wandering and breath focus for standard (C) and oddball (D) stimuli from 180 to 280 ms after stimuli presentation (corresponding to the yellow highlighted region on the ERP plots). Non-significant areas are grayed out in topographic maps and the black dot indicates the position of electrode Fz.

significant interaction between mental state and type of stimuli in this latency range. However, as shown below, we did observe such an interaction at earlier latencies.

We found a significant effect of the type of stimulus–oddball or standard–on the amplitude of the early ERP negative component between 90 and 120 ms after stimulus onset (Fig. 3). After presentation of an oddball stimulus the ERP is significantly more negative over frontal and temporal regions than after presentation of a standard stimulus both in the breath focus and mind wandering conditions (Fig. 3C and D). This increased negativity for oddball is usually termed mismatch negativity (Naatanen et al., 2007). The mismatch negativity (MMN) was larger during breath focus compared to mind wandering over the right frontal region (Fig. 3E). Supplementary Fig. 2 shows single subject average ERP values and standard error for both the 180 to 200 ms and 90 to 120 ms ERP range.

We then investigated event-related activity using time-frequency decompositions. The event-related spectral perturbation plot reveals increased theta band power (4–7 Hz) and decreased high alpha (10–14 Hz) and high beta (20–25 Hz) band power after stimulus presentation (Fig. 4). In general, statistical inference testing between the mind wandering and the breath focus state returned a lower *p*-value for standard stimuli compared to oddball stimuli—it might be a matter of number of observations since there was, on average, five times more trials for standard than for oddball stimuli. From 100 to 300 ms after standard auditory stimuli presentation, theta (4–7 Hz) power was significantly higher on frontal sites when subjects were mind wandering compared to when they were focusing on their breath. Delta (2–3.5 Hz) power 200 to 350 ms after standard auditory stimulation follows the same trend and we also observed a significant power increase for oddball stimuli at occipital and frontal sites. High beta (20–25 Hz) power from 100 to 300 ms after standard stimuli presentation is significantly higher on parieto-occipital sites during mind wandering compared to breath focus. Interestingly, despite large high alpha (10–14 Hz) evoked power to both standard and oddball stimuli, we did not observe any significant effect of the attentional state on the ERSP in this frequency band.

We also tested for difference of ERSP between standard and oddball stimuli during both the mind wandering and the breath focus states. Only beta band power from 100 ms to 300 ms after stimulus presentation differed significantly, being lower for oddball stimuli (not shown). This effect was not significantly different between the mind wandering and the breath focus states.

Discussion

Our study aimed at characterizing the neural correlates of spontaneous and task-unrelated mental activity (i.e. mind wandering) and its effect on sensory processing. Compared to a breath-focus mental state, we have shown that mind wandering is characterized by a power amplitude increase in the theta frequency band and a power amplitude decrease in the alpha and beta frequency bands. We also showed that, during mind wandering, standard auditory stimuli induce a higher power in the theta and delta frequency band over parieto-occipital regions and higher power in the high beta frequency band over frontal regions. The study of mean evoked related potentials revealed that the amplitude of the P2 positive ERP component is larger during mind wandering than during breath focus and that the MMN is of smaller amplitude during mind wandering than during breath focus. Taken together these results establish a strong link between the subjects' internal experience–mind wandering or breath focus–and distinct neural correlates.

Control task and novelty of the experimental design

The control task being used to study mind wandering was critical. We chose a breath focus task, which is a relatively neutral non-

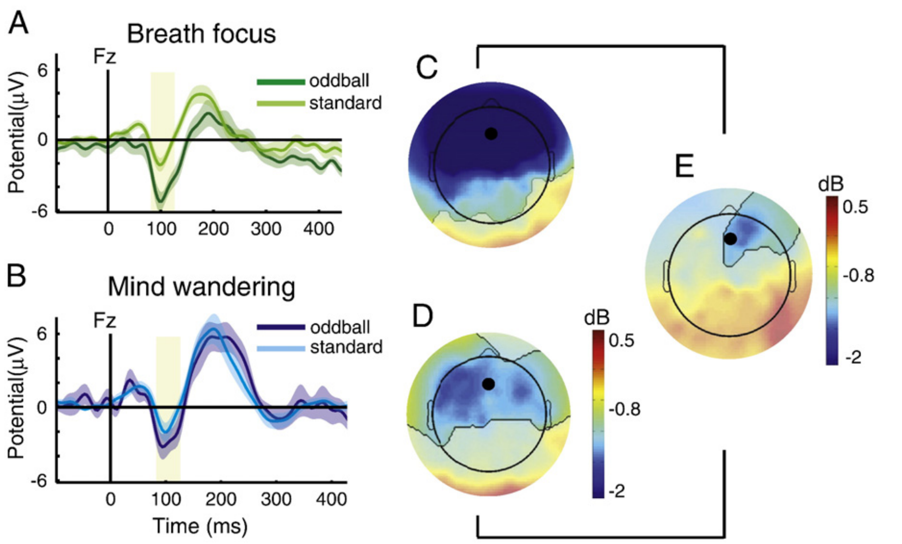

Fig. 3. Mismatch negativity during the mind wandering and breath focus states. (A, B) Grand-averaged ERP to standard and oddball stimuli for the breath focus and mind wandering state. As in Fig. 2, the shaded area surrounding each curve represents the standard error of the mean. (C, D) Topographical difference maps between the mean ERPs to oddball and standard stimuli (Mismatch negativity MMN) for the breath focus and the mind wandering state. (E) Topographical difference map between MMN maps in breath focus and mind wandering condition (map C–map D). Non-significant areas are grayed out on the topographic maps and the black dot indicates the position of electrode Fz.

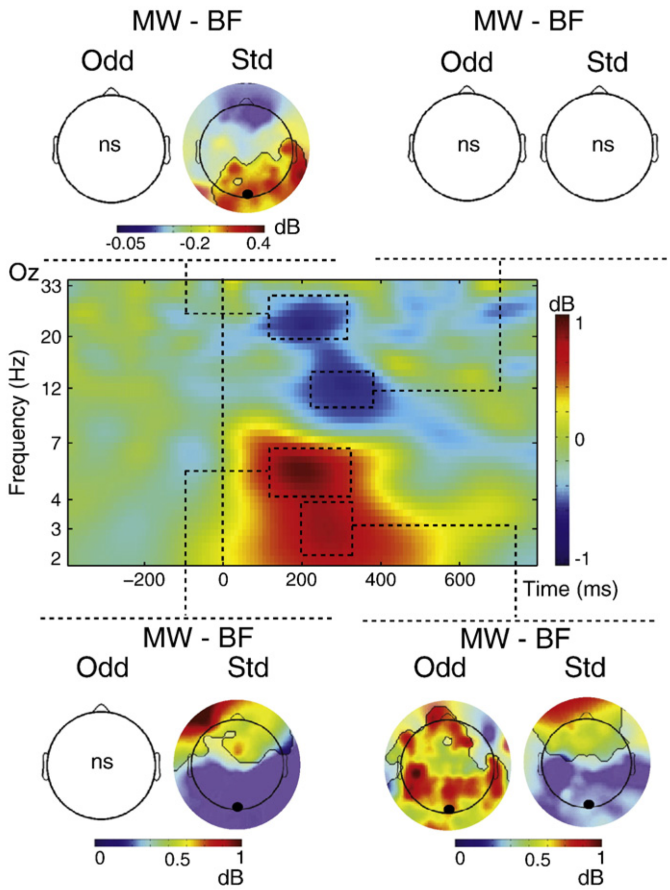

Fig. 4. Effect of attentional state and type of stimulus on event related spectral perturbation. The central panel indicates the grand-average ERSP at electrode site Oz averaged over both oddball (Odd) and standard (Std) stimuli for both the mind wandering (MW) and the breath focus (BF) state. Topographical maps of power difference between the mind wandering and the breath focus conditions are shown for oddball and standard stimuli at given time-frequency regions of interest (dotted rectangles). Shaded areas on the topographical maps represent non-significant regions. Topographical maps for which there were no significant electrodes are indicated using a blank map with the sign "ns" (non-significant). The black dot represents the position of electrode Oz.

cognitive task. Ideally, one would study mind wandering during several control attention engaging tasks. Here, we want to emphasize the difficulty and novelty of the experimental design and why it was impractical for us to use multiple control tasks. Other studies of mind wandering often use tasks where subjects have to respond continuously to stream of stimuli (e.g. Smallwood et al., 2008). By contrast, in our task, we asked subjects to press a button based on pure introspection. We wanted to collect as many behavioral responses as possible, but despite 1 h of recording for each subject, we only obtained 13–52 clean data epochs per subject. In addition, despite the instruction to stay still, subjects tended to exhibit muscle artifacts in their EEG after pressing the button, forcing us to reject about 25% of the data. Finally, subjects varied widely in their propensity to report mind-wandering events, and four subjects had to be excluded because they provided too few responses. This experiment was the first of its kind and is a proof of concept that, despite the difficulty encountered, this type of study is possible.

Brain states fluctuation at rest and spontaneous reports of mind wandering

The difference in EEG activity between mind wandering and breath focus is consistent with the Laufs et al. (2006) EEG-fMRI study showing that spontaneous EEG alternates between two states at rest. Our study refines Laufs' results by showing that the low frequencies (theta-delta) and high frequencies (alpha-beta) changes he observed may be associated to a transition between a state of concentration on processing external stimuli and involuntary mind wandering. Our EEG study further confirms that when subjects are engaged in a task, the brain can spontaneously shift into another alertness mode, which is most likely mind wandering.

fMRI bold signal during the resting state shows spontaneous fluctuations between a "task positive" network comprising brain areas activated during attention-demanding tasks and a "task negative" (or "default") network being activated during rest and deactivated during these tasks (Fox et al., 2005). Preceding reports of mind wandering, Christoff et al. (2009) found increased BOLD activity both in the default network (precuneus, ventral anterior cingulate cortex and temporoparietal junction) and in the frontal executive network. This result is consistent with an fMRI study showing increased amount of mind wandering linked to increased amount of activity in the task negative network (Mason et al., 2007). Continuous increase of BOLD activity in the occipital, frontal and temporal parts of the defaults network is also found during the transition from eyes-closed wakefulness to sleep (Olbrich et al., 2009). The higher occipito-parietal theta and fronto-central delta during mind wandering could thus be related to increased BOLD activity in these areas. Additional combined EEG-fMRI studies would be needed to establish a clearer link between EEG and BOLD signature of the mind wandering state and its relation to the default mode network, in particular regarding localization of the neuronal sources of the EEG rhythm correlated with the BOLD signal.

We also observed a delta power increase during mind wandering, an increase that we believe could be linked to decreased alertness. Spontaneous delta power increase has been linked to decreased performance during cognitive processing (Harmony et al., 1996). Spontaneous delta power increase has also been associated with decreased level of alertness in various experimental setups (Makeig and Inlow, 1993; De Gennaro et al., 2001; Caldwell et al., 2003). Moreover, as reviewed by Laufs et al. (2006) and shown in this report, delta power increase is associated with alpha power decrease, which has been associated with low stages of vigilance (Loomis et al., 1937; Roth, 1961). Note that 6 of the 12 subjects reported some level of drowsiness during the experiment. To be sure that our results did not pertain to drowsiness, Supplementary Fig. 3 shows the same time-frequency decomposition as Fig. 1 although it only includes subjects that did not report drowsiness. The time-frequency patterns of Supplementary Fig. 3 are almost identical to the ones visible in Fig. 1.

The meta-consciousness event allowing the transition from the mind wandering to breath focus state is finally marked by a transient increase of about 1 Hz of the alpha peak frequency and also by a more long lasting increase in alpha power. Re-directing the attention to the task requires increase working memory activity that has been shown to be correlated with alpha power increase (Jensen et al., 2002), a power increase that may index re-activation of thalamo-cortical pathways (Schreckenberger et al., 2004). The alpha-peak frequency increase may also be a marker of the attentional switch between mind wandering and the focused task since Angelakis et al. (2004) suggests that increase of peak alpha frequency might represent a state of "cognitive preparedness".

MMN, attention, alertness, and mind wandering

The study of evoked related potential shows an increased negativity at frontal electrode sites for the ERP of oddball compared to the ERP of standard stimuli from 90 to 120 ms after stimulus presentation. This result corresponds to the mismatch negativity (MMN) usually described as negative brain response to the sensory detection of a sudden change in the flux of auditory perception (Naatanen et al., 2007). The MMN typically occurs approximately 100 to 150 ms after stimulus presentation and is centered on fronto-central electrodes sites (Naatanen et al., 2007). The amplitude of the MMN is modulated by the direction of the subject's attention (Sabri et al., 2006), and is larger when the attention of the subject is directed toward the auditory stimuli (Alain and Woods, 1997). Our results show the MMN amplitude is lower during mind wandering compared to breath focus, which suggest a disengagement of the attention from stimuli processing during mind wandering.

The reduction of the MMN is also characteristic of drowsiness and the early sleep stages (Sallinen and Lyytinen, 1997; Nittono et al., 2001), which supports the idea that the mind wandering state is associated with decreased vigilance. This also suggests that mind wandering may share common traits with the decreased alertness characterizing the transition from wake to sleep (Sabri et al., 2003). Note that we did not observe in our data the late negativity at about 300 ms after stimulus presentation that accompanies advanced states of drowsiness leading to sleep or sleep itself (Winter et al., 1995; Campbell and Colrain, 2002). This suggests that our subjects were not deeply drowsy. Mind wandering could thus correspond to an early state of drowsiness of decreased alertness and vigilance.

Late stimulus evoked activity and disengagement of attention from stimuli processing during mind wandering

ERP analysis also reveals that the amplitude of the positive component at about 200 ms (P2) is larger during mind wandering than during breath focus. This effect is also present, although to a lesser extent, in Cahn (2007) who found a P2 component larger for distracting stimuli when subjects were actively reactivating autobiographical memories–which may be considered similar to mind wandering–compared to when they were practicing meditation. Increase of the P2 component to auditory stimulus has also been associated with the disengagement of subjects' attention toward stimuli (Naatanen and Picton, 1987) and is also characteristic of the sleep onset period (Campbell and Colrain, 2002). Again, this result is consistent with attentional disengagement toward stimuli processing during mind wandering.

We did not observe a P300 ERP component associated with the presentation of the rare stimuli in our passive auditory oddball task. P300 is best observed in active experimental design where the subjects have to respond to rare targets and is usually hardly visible in passive oddball paradigms (Cahn and Polich, 2009). However, using an active task, Smallwood et al. (2008) showed a reduction of the P300 ERP during mind wandering. Consistent with our MMN and P2 results, Smallwood et al. (2008) results suggest a disengagement of attention towards external stimuli processing.

The study of ERSP is harder to interpret since it is rarely presented in literature. Increased evoked theta frequency over frontal regions may be related to increased autobiographical memory engagement during mind wandering (Jensen and Tesche, 2002; Onton et al., 2005). Note that the ERP differential scalp maps from 180 to 280 ms were similar to the theta frequency maps with strong changes over occipital regions. The ERP is a complex combination of stimulus-locked phase synchronization and spectral amplitude increase (Makeig et al., 2002; Delorme, Westerfield et al., 2007). We tested if ERP and ERSP activities were linked by computing the correlation between the ERSP activity and the ERP at electrode site Fz for the evoked delta, theta, alpha and beta frequency band activity shown in Fig. 2. We did not find any correlation between the early ERP negative component between 90 and 120 ms after stimulus onset and any of the ERSP components. However, when pooling data for both types of stimulus and both attentional states, we did find a positive correlation ($p<0.001$; $df=47$; paired t-test) between the evoked delta (2.5 to 3.5 Hz) and high alpha (10–14 Hz) activity 100 to 300 ms after stimulus onset and the late ERP positive component at 180 to 280 ms. This indicates that both the late ERP complex and delta ERSP activity may index similar processes in our passive auditory oddball task.

Function of mind wandering

The functional role of mind wandering remains debated in philosophy and experimental psychology. The concept of mind wandering plays an important role in Buddhist psychology (Trungpa, 2004) since it is a major obstacle to concentrative meditation practice. Buddhist psychology argues that mind wandering is a non-productive ego-centered state, a state of “sleep” where our unconscious constantly rehash the same thoughts and beliefs creating confusion and strengthening our sense of self. By contrast, some researchers have suggested that mind wandering may be useful to provide creative insight (Christoff, Gordon et al., 2009) in a way similar to sleep-induced insight (Wagner, Gais et al., 2004). Our result of finding mind wandering to be a state of low alertness supports both views. It can be considered a state of low concentration or relative “sleep” as argued in Buddhist psychology but it could also be seen as a hypnagogic state that may lead to creative insights (Boynton, 2001). We believe that by studying the common brain structures and dynamics involved in mind wandering, meditation, self, and creativity, brain-imaging techniques could help bring new light to this debate.

Based on our results and previous studies, we conclude that mind wandering is a low-alertness state of rest. If mind wandering corresponds to a state of rest, one hypothesis is that subjects who are sleep deprived might spend more time mind wandering during the day. The time that a subject spends mind wandering may be estimated using probe-caught mind wandering techniques. Smallwood and Schooler (2006) place a distinction between self-caught and probe-caught mind wandering episodes. Self-caught mind wandering is the type of mind wandering studied in this report. By contrast, to assess the amount of time subjects spend mind wandering while being unaware of it, they may be probed at regular intervals about their state of mind wandering. We would thus anticipate that probe-caught mind wandering frequency would increase with the amount of sleep deprivation. Finally, if the activity in the default network is linked to mind wandering as previously claimed (Mason, Norton et al., 2007; Sonuga-Barke and Castellanos, 2007), we would expect that the activity in the default network during the day would also increase with sleep deprivation. Further studies should be able to verify or disprove these hypotheses.

In conclusion, we have shown the neurophysiologic markers of mind wandering. Based only on subjective reports about mind wandering, we have established that two different attentional states correspond to two distinct brain states underlying different modes of sensory processing. Our results suggest that mind wandering correspond to a state of rest, a state of low vigilance where stimulus evoked responses are reduced. This study is one of the first event-related neuroimaging study to rely only on behavioral responses based on pure–not stimulus induced–introspective subjective reports. It further demonstrates that neuro-phenomenological approaches to the study of subjective experience are possible in neuroscience (Lutz and Thompson, 2003) yet argues for the need of a more fine-grained taxonomy of private mental states.

Supplementary materials related to this article can be found online at doi:10.1016/j.neuroimage.2010.10.008.

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Appendix D

Book chapter : Meditation and Neuroscience : from scientific research to clinical applications

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Chapter 27
Meditation and Neuroscience: From Basic Research to Clinical Practice

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2. Private practice of Dr. Hahusseau, 12 grande rue Nazareth, 31000 Toulouse, France

Meditation has been extensively practiced in many civilizations for thousands of years as a means of cultivating a state of well-being and for religious purposes. It has now started to be studied in terms of its influence on the brain and body and used in clinical settings. This chapter will first review meditation effects at the physiological, attentional, and affective levels and the scientific paradigms used to study these effects. A clinical application on emotion regulation will then be presented.

Spiritual practices that aim at transcending the common state of consciousness can be found in human societies all over the world down to shamanic practices in the Paleolithic (Walter & Neumann Fridman, 2004; Winkelman, 2000). Formal references to meditation can be found in ancient texts as early as the third century BCE in the Buddhist wittings of the Abhidharma (Cox, 2004). Today, “meditation” is used as a generic term to refer to a wide range of practices for self-regulation of emotion and attention (Gunaratana, 2002) and is considered an inherently experiential practice present in most religious or philosophical traditions. Meditation generally involves focusing one’s attention on a particular physical or mental object. When mind wandering occurs, practitioners are instructed to bring their attention back to the meditative task. Meditation practices often involve altered states of consciousness although these typically only arise during intensive practices of several hours a day. Meditation practitioners often perform daily meditation for a period of time ranging from 15 minutes to several hours, with the goal of getting insight into the nature of their minds and the universe or reaching a state beyond the materialistic world and connecting with the infinite (or a divinity, depending on the meditation tradition).

Based on the assumption that different conscious states are accompanied by different neurophysiological states, a neuroscientific approach to meditation focuses on altered sensory, cognitive, and self-awareness experiences. Meditation-induced neurophysiological changes may be of two kinds. Changes that occur during meditation practice are referred as state changes. Changes which build up over months or years and persist even when the mind is not actively engaged in meditation are referred to as trait changes (Cahn & Polich, 2006). . On one hand, the study of meditation states is especially relevant for consciousness research as a means of exploring the effect of meditation itself on the brain. On the other hand, the study of meditation traits is more particularly adapted to the study of meditation’s beneficial effects on health and general well-being in association with potential clinical applications.

There are a large number of distinct meditative practices, but given that self-regulation of attention is a major component that is common among all of them, it is possible to classify meditative style on a continuum, depending on how attentional processes are directed (Cahn & Polich, 2006). Lutz, Slagter, Dunne, and Davidson (2008) proposed a theoretical framework in which meditation practices are categorized in two main groups. Concentrative—or focused attention—techniques involve continuous sustained attention on a selected object: the object of focus may be breath or body sensations, a subvocal repeated sound or word (mantra), or an imagined mental image. Focused attention meditation requires the narrowing of awareness so that the mind only contains the object of focus. On the other hand, mindfulness meditation practices, also called open-monitoring or insight meditation, involve the expanding of awareness with no explicit focus (except awareness itself). In mindfulness, practitioners are instructed to allow any thought, feeling, or sensation to arise in consciousness while maintaining a nonreactive awareness to what is being experienced. Mindfulness may be described as sustained awareness aimed at nonreactive and nonattached mental observation, without cognitive or emotional interpretation of the unfolding moment-to-moment experience (Cahn & Polich, 2006; Gunaratana, 2002; Kabat-Zinn, 2003; Lutz, Slagter, et al., 2008).

Different Types of Meditation

Meditation traditions exist all over the world. A lengthy and exhaustive review would be necessary to attempt to describe each and every one of them, so this chapter will focus on only a few of them, mostly from Asian traditions, since these are the traditions that have been studied the most by Western scientists.

Soto Zen is a tradition based on mindfulness and open awareness. One practices it while sitting, usually facing a wall with open eyes. Practitioners are instructed to observe their thoughts and emotions as they arise in their minds and not to cling to them or engage in narrative thinking but simply let these thoughts or emotions go and remain purely aware of sitting. Every time practitioners realize that the mind has started to wander (i.e., they identified with a thought), they have to bring their attention back to the present moment. This practice is also called Shikantaza, a Japanese term that means “nothing but precisely sitting.”

In Rinzai Zen, the other major form of Zen practice, practitioners are instructed to concentrate on koans. Koans are riddles that cannot be solved with knowledge or thinking. “What is the sound of one hand clapping?” is a popular Zen koan. Zen students are given a koan by a Zen teacher, depending on their level of development in the practice and their personality. They are then instructed to meditate on it until they can solve it. They regularly present their solution to their teacher and, if successful, are given a new koan. Koans are ways to help meditators get out of the thought-based state of ordinary consciousness and access pure awareness of the present moment.

Vipassana meditation is another meditation technique that is now widespread in the West. In Vipassana, practitioners begin by observing their breath around the area of the nostrils to help the mind develop sustained, focused attention. Every time the mind wanders, they have to bring it back to the sensation of breathing. As they do so, attention gets sharper and sharper. Then practitioners have to mentally scan sequentially and meticulously each part of the body and feel the sensation in each of these body parts . They continuously keep their attention moving down from head to toes and then up in the reverse direction. At first, they find it hard to experience sensation in each and every part of the body, but with practice, they progressively come to feel sensations in more parts of their bodies. Participants are only instructed to keep their attention moving and observe, objectively and with equanimity, the sensations that they are experiencing. Practitioners should try to avoid developing feelings of aversion or cravings for specific sensations, as this is believed to disturb both body and mind. Vipassana is a good example of a meditation practice in which focused attention and open monitoring are both incorporated.

Mantra or prayer meditation might be the most popular type of meditation worldwide and is present in Tibetan Buddhism, Sufism, Hinduism, and many other traditions. It became widespread in the West in the 1960s with the development of transcendental meditation (TM). A mantra is a religious or mystical sound, word, or poem that can be either recited aloud or subvocally. For instance, Hare Krishna practitioners are instructed to repeat the 16-word Hare Krishna mantra, "Hare Krishna Hare Krishna, Krishna Krishna Hare Hare, Hare Rama Hare Rama, Rama Rama Hare Hare," 1,728 times a day, keeping the correct count with the help of prayer beads. The particular body vibration that a mantra induces is believed to calm and focus the mind and body without the need for intense concentrative efforts. When meditators repeat the mantra, they are instructed to focus their full attention on the recitation, and also sometimes on its meaning if it has one. Some practices involve mantra repetition with awareness of the breath (and others without breath awareness). As with other types of meditation, when meditators experience mind-wandering episodes, they are simply instructed to bring their attention back to the mantra.

Mantra meditation is in many ways similar to slow reading or chanting of sacred texts while one absorbs their meaning. These practices are present in all religions and spiritual traditions. Texts involved may be sutras in Buddhism (discourse from the Buddha). Christian practices, for instance, involve recitation of a prayer phrase or the study of Scripture, which involves the slow reading of the Bible as the reader considers the meaning of each verse, and is practiced by monks of various orders. Although these practices are usually not specifically referred to as meditation, they involve focused attention and going beyond dialectic thinking, two traits they share with meditation.

Other forms of meditation may involve generating and focusing on feelings of loving-kindness or compassion toward all living beings (one of many Tibetan Buddhism practices). Mental visualization and careful examination of sacred objects is another common mediation practice in Tibetan Buddhism. Different practices can also be done while one is moving. In the case of walking meditation, one has to walk slowly, keeping breath coordinated with each step, and remain aware of every body sensation and movement. While working or doing simple tasks, one may simply be present and focused on the action being done now, that is, giving the present moment one's undivided attention, without thinking about past or future events. Walking and work meditation are an important part of Zen practice. Yoga is also a form of meditation in movement. It combines specific physical postures, breath patterns, and body awareness.

In most meditation traditions, daily practice is supplemented by retreats that involve intensive practice. These retreats are often held in complete silence. They can last from a few days to several months or even years. In the Tibetan meditation tradition, for instance, it is not uncommon to see dedicated practitioners engage in monastic life spending several years of their lives in complete silent isolation.

Finally, practices have been adapted for clinical use based on traditional forms of meditation. An example is Jon Kabat-Zinn's mindfulness-based stress reduction program (Kabat-Zinn et al., 1992). This program involves a daily meditation practice and is usually taught in 2-hour weekly classes over a period of 8 weeks, including a full day of meditation.

History of the Scientific Study of Meditation

Meditation has been the subject of scientific research for about the past 40 years but only started to gain popularity in the late 1990s (figure 27.1). The neuroscientific study of meditation has involved both fundamental and clinical research and aims at understanding how mental training affects the brain, the body, and overall health. In fundamental research, experience-induced changes in brain activity and anatomy, that is neuroplasticity, are a major focus of study (Bourgeois, 2005; Draganski, Gaser, Busch, Schuierer, Bogdahn, & May, 2004). Interestingly recent results suggest that meditation, which is a purely mental activity, may also induce brain plasticity (Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). As it often triggers altered states of consciousness, meditation also holds an important place in the experimental framework of consciousness research (Lutz, Dunne, & Davidson, 2007; Thompson, 2006; Varela, Thompson, & Rosch, 1999). Both of these fields have benefited from the development of brain-imaging techniques (fMRI, PET, EEG, MEG) and progress in signal analysis (Friston, 2002; Lachaux, Rodriguez, Martinerie, & Varela, 1999; Makeig, Debener, Onton, & Delorme, 2004). These technological improvements allow for a better characterization of dynamical interactions in the brain and thus enable scientists to study problems that have long been relegated to the realm of philosophy, such as the question of consciousness. These recent developments, together with the development of medical practices incorporating meditation in therapeutic protocols—and thus the need to validate meditation’s impact on the brain and body—account for the recent popularity of meditation studies in neuroscience research.

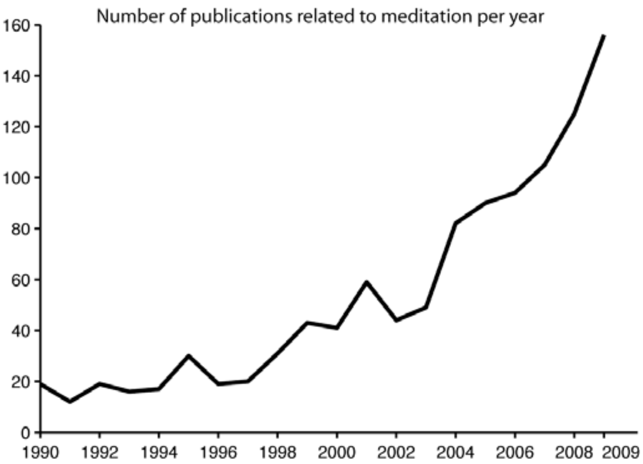

Figure 1. Search results for the term “meditation” from PubMed, 1990–2009

Scientific interest in meditation also reflect a recent shift in cognitive science toward viewing the integration of consciousness and first-person experience as a valuable object of scientific investigation. At the end of the 19th century, the importance of subjectivity and introspection were emphasized both in philosophy by Husserl (1936/1970) and in the scientific study of mental phenomena by William James (1890/1983). However, during the following decades, science attempted to reduce cognition and all mental phenomena to their observable consequences in the world. In the first part of the 20th century, behaviorists praised the study of the mind in examining behavioral performances and electrophysiological responses. Behaviorism led to a complete rejection of subjectivity and private experience, which were judged to be outside of the field of science. The development of cybernetics around 1940–1950 and the subsequent birth of cognitive science led scientists to regard the brain as an information-processing unit, and the architecture of the first computers was used as a model for the brain. Even though the work of Gestalt psychologists (Koffka & Schoen, 1955) and phenomenological philosophers such as Merleau-Ponty (1995) attempted to develop more subjective approaches to the mind, the reductionist approach to cognition has had a lasting influence on cognitive science. In the last two decades, the development of embodied and situated approaches to the mind has encouraged reconsideration of the body’s role as well as first-person experience in cognition. These approaches view cognition as arising from the coupled interactions of the brain, body, and environment (Damasio, 1994; Varela et al., 1991). This shift has been accompanied by the renewed use of subjective data in experimental protocols (Jack & Roepstorff, 2003; Varela & Shear, 1999). Coming from the embodied cognition perspective, which sees first-person experience as critical to a complete understanding of the mind, Varela developed the neurophenomenology approach, which combines first-person report of subjective experience with experimental study of brain activity (Lutz et al., 2007; Thompson, 2006).

The neurophenomenology approach to meditation has been successfully applied in experimental studies of visual perception (Lutz, Lachaux, Martinerie, & Varela, 2002), in which subjects were extensively trained to report their subjective experience during a psychophysical visual task. For meditation to be integrated into experimental studies, neurophenomenology needs precise and reliable subjective descriptions of the mind during the meditative state. The neurophenomenology approach to meditation was adapted from Buddhist meditative psychology concepts (Lutz et al., 2004; Raffone et al., 2007; Varela et al., 1991). Buddhist meditative traditions, like many others, are based on mental training of capacities for sustained, attentive awareness of the moment-to-moment flow of experience, a practice that is supposed to allow the practitioner to develop deep insight into the nature and functioning of the mind and consciousness (Dreyfus & Thompson, 2006; Gunaratana, 2002). The basis of Buddhist meditative psychology is directly based on reports from expert meditators and is supposed to be empirically testable. While still in its infancy, neurophenomenology will certainly help us understand consciousness and bridge the gap between brain neural dynamics and subjective human experience (Rudrauf, Lutz, Cosmelli, Lachaux, & Le Van Quyen, 2003; Thompson, 2006; Varela et al., 1991).

Meditation and the Peripheral Nervous System

Since meditation is often considered to be a relaxation technique, it is reasonable to assume that meditation practice affects the functioning of the body. The mechanisms underlying the effect of meditation on the body are not yet understood, and as for cognitive and brain activity correlates of meditation, we currently lack formal evaluation procedures for the diverse meditation types and methodologies being used (Cahn & Polich, 2006). We will thus only provide a brief overview of interesting research directions.

Body Representation

Meditation induces long-lasting changes to one's body perception that can be observed both at low-level cortical representations and at higher-level representation associated with the sense of self (Cahn & Polich, 2006).

Meditation-induced changes in cortical areas devoted to process inputs from the body are reported by Lazar et al. (2005) and could account for increased awareness of the sensory field. Lazar et al.'s study shows that regular practice of open-monitoring meditation—which focuses on both internal and external sensations—increases the thickness of the cortex in somatosensory areas of the brain. This increase in cortex thickness was positively correlated with meditation experience, so we may hypothesize that it functionally corresponds to an increase in body awareness. Testing this hypothesis, Khalsa, Rudrauf, Damasio, Davidson, Lutz, and Tranel (2008) had long-term meditators in both active (yoga) and sitting forms of meditation and non-meditators perform a heartbeat detection task in which participants had to tell whether or not short sounds were displayed synchronously to their own heartbeats (they had to try to feel their heartbeats without using their finger on peripheral arteries). He found that the meditators did not perform any better than the non-meditators. This suggests that changes in meditators' body representation are not functionally correlated with better perception of physiological sensation. However, in this study, meditators systematically rated their experience of interoceptive perception higher than did control subjects. Collection of their subjective experiences also revealed that they found the heartbeat-counting task to be easier than non-meditators did. Lazar et al.'s results might then directly index improved body awareness without improved body representation.

Meditation practice also induces changes in one's representation of the self. An fMRI study by Farb et al. (2007) showed a decreased coupling between the insular cortex, which is involved in the perception of pain and internal body responses, and the medial prefrontal cortex (mPFC), which is involved in higher-level cognition, after an 8-week open-monitoring meditation program. This suggests the presence of a different type of self-awareness in meditation practitioners that is less rooted in one's sense of body and more oriented toward an "impersonal beingness" (Cahn & Polich, 2006).

Effect of Meditation on the Autonomic and Immune System

Meditation affects bodily functions in two different ways: standard daily meditation practice creates a low arousal state, and peak meditation experience fosters a high arousal state. According to early theoretical models, infrequent peak experiences have quite a different high arousal tone than the more common meditative states (Cahn & Polich, 2006), but it is difficult to study such experiences because of their rarity. This section will thus only review data concerning the usual trait commonly experienced during meditation practice. Based on early studies of transcendental meditation, Jevning, Wallace, and Beidebach (1992) qualify the common meditation state as a "wakeful hypometabolic state."

The autonomic nervous system controls the activity of organs and viscera in the body. It is composed of the sympathetic and parasympathetic neural pathways. Although this is a schematic view and the reality is far more complex, these two components are usually believed to have opposite actions on their targeted organs or tissues. The sympathetic system is most often involved in energy mobilization, preparing the organism to react (flight-or-fight response, response to stress), whereas the parasympathetic component is responsible for most resting and restoration functions (rest and digestive functions) of the organism (Jänig, 2003).

One possible way for meditation to act on autonomic activity is through respiration control. Respiration is one of the body's few autonomic functions that can be controlled and can affect functioning of the autonomic nervous system (Badra et al., 2001; Eckberg, Nerhed, & Wallin, 1985). Many meditation traditions consider breath, body, and mind to be linked and thus have given, whether explicitly or not, the breath a central role in meditation practice. Voluntary control of the breath may be achieved through specific inhalation-exhalation rhythmic patterns, as in pranayamic practice and the slow diaphragmatic breathing practiced in yoga that involves specific movement of the thoracic cage. Breath also tends to involuntarily slow down during mantra chanting (Bernardi et al., 2001), breath-counting meditation, and simple awareness of the breath (Lehrer, Sasaki, & Saito, 1999).

Slower respiration rate during meditation practice induces changes in cardiovascular activity that correspond to an increase in the activity of the restorative parasympathetic system (Saul, 1990). This increased parasympathetic activity has also been assessed through the slowing down of basal heart rate in meditators (Pal, Velkumary, & Madanmohan, 2004) and the increased synchronization, or respiratory sinus arrhythmia (RSA), between the breathing cycle and the heartbeat during meditation (Cysarz & Bussing, 2005; Ditto, Eclache, & Goldman, 2006). RSA corresponds to high variability in heart rate as heart rate becomes faster during inhalation and slower during exhalation. Mechanisms behind human RSA are not yet well understood (Grossman & Taylor, 2007; Tzeng, Sin, & Galletly, 2009) but might be important to meditation research, as RSA could be used as an index of successful emotion exposure during meditation (see the section on emotion, below).

Slow breathing has also been associated with increased baroreflex sensitivity (Joseph, Casucci, Casiraghi, Maffeis, Rossi, & Bernardi, 2005; Reyes del Paso, et al., 2006). Decreased blood pressure is often reported after meditation practice by both healthy individuals and hypertension patients (Carlson, Speca, Faris, & Patel, 2007; Manikonda et al., 2008). Improved control of blood pressure is usually considered a sign of balance between parasympathetic and sympathetic activity. Finally, since one role of sleep is to restore the balance in these autonomic systems, the fact that meditators typically require less sleep than control subjects (Ajaya, 1976) suggests a better balance between these two systems.

Although few studies have been conducted, there is increasing evidence that meditative practice also affects the immune system. Psychological states such as stress affect the functioning of the immune system (Segerstrom & Miller, 2004). The immune system is indirectly under the influence of the central nervous system via hormonal signaling and through activity of the autonomic nervous system (Dantzer & Kelley, 1989; Jänig, 2003). Davidson et al. (2003) found faster peak rise for the antibody response to a flu shot among healthy meditators who underwent an 8-week mindfulness-based stress reduction (MBSR) training course in open-monitoring meditation than among non-meditators. Increased number and increased activity of lymphocyte T and other natural killer cells have also been found in HIV patients after MBSR training (Robinson, Mathews, & Witek-Janusek, 2003; Taylor, 1995). Finally, in a recent study, Pace et al. (2009) assessed the effect of compassion meditation (in which one works at developing altruistic emotions and behaviors towards all living beings) on the immune response and found a negative correlation between the amount of meditation practice and induced stress immune response.

We should develop a better understanding of meditation effects on the autonomic and immune systems as we improve our understanding of these systems' relationship and their dynamic links to the central nervous system. Study of slow oscillatory activity in both the central and autonomic systems would likely shed light on coupling mechanisms between the brain, vegetative functions, and the mind (Basar, 2008). Jerath, Edry, Barnes, and Jerath (2006) built a model of synchronization between the cardiopulmonary and the central nervous systems to explain how slow, deep pranayamic breathing practiced in yogic meditation can influence the autonomic nervous system. Davidson et al. (2003) also found that left-sided anterior oscillatory activity of the brain is positively correlated with activity of the immune system after meditation practice, assessing through the quantity of natural killer cells. This type of hemispheric activity has also been correlated with both the autonomic system activity and emotional regulation (Craig, 2005), as we will see in the section dealing with emotions. Thus, although a growing body of evidence showing a link between mind and body states has accumulated over the years, more research will be needed to unravel the mechanisms underlying the effects of meditation on the autonomic and immune systems.

Meditation and Aging

As we have seen, meditation training seems to protect against stress and boosts the immune system. It has also recently been shown to reduce neuronal decay due to normal aging. Pagnoni and Cekic (2007) found greater prefrontal cortex thickness in middle-aged meditators than in non-meditators, as well as a decline in cortical thickness associated with age, a result that is also reported by Lazar et al. (2005). Nagendra, Sulekha, Tubaki, and Kutty (2008) also showed that expert Vipassana meditators did not present sleep patterns associated with aging. Both the length of the slow waves sleep period before the occurrence of the first REM sleep episode and the total length of REM episodes typically decrease with age. They showed that this decrease was drastically smaller in meditators of age 50–60 than in control subjects of the same age. This suggests that meditation slows down the brain-aging process through a mechanism that has yet to be discovered.

Meditation and Attention

The cognitive function that meditation may affect the most is attention, since meditation is a form of attention training. Meditation is a skill and as such it may train attentional systems. As physical training strengthen body muscles, mental training involved in meditation reinforces brain attentional circuits. Meditation recruits attentional brain areas involved in learning. Using fMRI, a technique that monitors metabolic activity in the brain as reflected by variations in blood flow, Brefczynski-Lewis, Lutz, Schaefer, Levinson, and Davidson (2007) found that in a group of Tibetan Buddhist meditators, focused attention meditation is associated with greater activation in multiple attention-related brain regions (dorsolateral prefrontal cortex, superior frontal sulcus, and intraparietal sulcus). Interestingly, brain activation varied based on the person's level of expertise. Expert meditators had less activity in attention-related brain regions, whereas greater activity among less expert meditators was associated with skill acquisition. This reduced metabolic activity in attention-related regions of highly expert practitioners suggests an effortless—though efficient—strategy for attentional resources allocation. This is supported by traditional Buddhist descriptions of a decreased need for voluntary attentional effort to attain concentration for expert practitioners. Using electroencephalography, Lutz et al. (2004) also found that brain activity varies based on expertise. These results suggest that meditation is a technique that is learned and perfected over years of practice.

According to Lutz, Slagter, et al. (2008), meditation practices involve at least three attention regulation subsystems. First, meditation may involve intense object-based concentration. Selective attention—or orienting—is the selection of specific information from the flow of sensory input and involves cortical structures known to gate information, such as the temporal-parietal junction, the ventrolateral prefrontal cortex, the frontal eye field, and the intraparietal sulcus (Corbetta & Shulman, 2002). Second, meditation imposes continuous monitoring of the focus of attention. Sustained attention—or alertness—is the maintenance of a state of high sensitivity to a perceived stimulus or mental object over time and most likely involves sustained synchronous activity between the thalamus and the right frontal and right parietal cortical structures—also known as the thalamo-cortical loop (Berger, Kofman, Livneh, & Henik, 2007; Coull, 1998; Posner & Rothbart, 2007). Finally, meditation also involves transient attention shifts, as when one disengages attention from a source of distraction and redirects it to the intended object of concentration (Cahn & Polich, 2006; Lutz, Slagter, et al., 2008). This involves executive attention—or conflict monitoring—which is the monitoring and resolution of conflicts among thoughts, feelings, and mental plan. This function is managed by the dorsal anterior cingulate cortex and the dorsolateral prefrontal cortex, structures that have also been shown to be activated when one is self-conscious (Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004; Weissman, Roberts, Visscher, & Woldorff, 2006).

Meditation Improves Perceptual Attention Capacity

Perceptual pre-attentive processes are sometimes under voluntary control—as, for instance, when we focus our attention on an object or sound—although they may also be affected by environmental cues. Selective visual attention focused on an object may be involuntarily influenced by the surrounding objects; for example, distracting visual stimuli of high contrast have been shown to automatically redirect this type of attention (Friedman-Hill, Robertson, Desimone, & Ungerleider, 2003). Below, we show how meditation affects involuntary allocation of low-level attentional resources.

In the auditory domain, pre-attentive processes involve the automatic detection of environmental changes and can be studied in the laboratory through the brain's electrical response (event-related potential) to a flow of frequent auditory stimuli interspaced with infrequent ones. The amplitude of the differential electrical activity between frequent and infrequent stimuli, called mismatch negativity, was found to increase immediately among expert practitioners after a focused attention meditation session (Srinivasan & Baijal, 2007). Similar findings were found for Vipassana meditation (Cahn, 2007). Focused attention training and the higher degree of awareness of the body and sensations induced by meditation might be responsible for increased sensory cortex sensibility. According to one interpretation, neuronal populations tuned to different stimuli inhibit each other and compete for attentional resources (Näätänen, 1992). Neuronal populations tuned to properties of the standard stimulation respond less vigorously upon repeated stimulation and become desensitized. Thus when a deviant activates a distinct new neuronal population, these fresh afferents respond more vigorously, eliciting mismatch negativity. Meditation would make these perceptual systems sharper and more sensitive.

Experimental work also shows that open-monitoring meditation increases processing capacity in the visual system. This evidence comes from a study using the attentional blink paradigm. In this paradigm, two stimuli are presented in close succession. As a result of allocation of all attention resources to the first stimulus, the second one is often not perceived. However, both behavioral and event-related potential results show that intensive 3-month open-monitoring retreats decrease the attentional engagement in processing the first target, thus allowing subjects to process and perceive the second one (Slagter et al., 2007).

These results indicate that meditation tends to boost low-level attention. This could be due to increased attentional resources. Meditation could recruit new attention-dedicated neuronal networks or strengthen existing ones. Another hypothesis is that attentional resources are constant. However, since meditation tends to quiet the mind, we may observe a disengagement of attention from higher cognitive and verbal areas. If attentional systems are not dealing with thought affects, they might have more resources to deal with low-level perceptual systems.

Meditation Decreases Perceptual Habituation

Neural and perceptual systems tend to habituate to repetitive presentation of stimuli, to which early responses are larger than later ones. Meditation has been shown to decrease perceptual habituation to repetitive stimuli. This type of effect has been mostly observed in open-monitoring meditation, in which the practitioner develops attention to the present moment-to-moment experience without allowing his or her attention to wander. In this meditation, each stimulus is seen as fresh and new in the present moment. As an individual practicing open monitoring works on perceiving each experience as it arises in the moment without judging, it might cut off automatic brain mechanisms responsible for habituation, establishment of routines, and action scenarios. A classical habituation paradigm involves repetitively presenting the same stimulus and observing the decrease in the induced 10-Hz brain alpha wave amplitude with the number of stimulus presentations. Non-habituation was demonstrated with open-monitoring meditators where the electroencephalographic alpha rhythm amplitude did not decrease after repeated stimulus presentations (Deikman, 1966; Wenger & Bagchi, 1961). These findings are also consistent with Cahn's study (2008) showing less automated recruitment of frontal attentional circuits when rare and salient auditory stimuli are processed during Vipassana open-monitoring meditation practice.

Open-monitoring meditation also allows for faster reallocation of attentional resources. Valentine and Sweet (1999) used an auditory sustained attention task in which participants had to mentally count the number of beeps in several series of tones presented at different rates. In general, fast series came unexpectedly. Open-monitoring meditation resulted in better counting performance in the unexpected fast series. Interestingly, this effect was not observed with focused attention meditation. One explanation is that practitioners of concentrative meditation might have focused intensively on the slow series and may have difficulty shifting their attention to start counting the faster series. On the other hand, open-monitoring practitioners, who only partially practice engaging their attention, could more easily shift their attention to the fast presentation rate.

These results indicate that meditation allows for non-habituation and faster reallocation of attention. Beyond low-level attention allocation, we will see now that meditation also has unexpected effects on the activity in higher perceptual areas.

Meditation Reduces Neural Population Competition in Higher Perceptual Areas

Carter, Presti, Callistemon, Ungerer, Liu, and Pettigrew (2005) reported results of a study of 23 Tibetan Buddhist monks who have been engaged in either focused attention or open-monitoring meditation. These monks were asked to perform a "binocular rivalry" task during which they were presented with two images, one before each eye. Under these circumstances, they were randomly experiencing either both images simultaneously or each of them alternatively for 2–3 seconds as the images competed for attentional resources in the visual system. No effects of open-monitoring meditation were observed either during or after the practice. However, monks practicing focused attention meditation were able to maintain a stable, superimposed percept of the two competing images for a longer than normal duration. These results suggest that selective and sustained attention allows conflicting stimuli to be perceived simultaneously by long-term expert practitioners both during and following focused attention meditation. This also points to the remarkable influence of meditation training on the brain, as no other mental training has been shown to affect allocation of attentional resources responsible for binocular rivalry.

Open-monitoring meditation also seems to allow meditators to more efficiently process stimuli competing for attentional resources. The Attention Network Test has been used to assess open-monitoring meditation influence on attentional subsystems. The test has subjects indicate the direction of a target arrow surrounded by flanker stimuli that either point in the same or reverse direction, thus inducing perceptual conflict (Fan, McCandliss, Raz, & Posner, 2002). Results show that after 5 days of open-monitoring meditation training, participants improved their performance in responding to trials with conflicting conditions (Tang et al., 2007). Both of these experiments show that meditation helps to efficiently process different conflicting stimuli.

Meditation and Higher-Level Attention for Monitoring Mind Wandering

What meditation practice brings to awareness is the presence of private thoughts and feelings that constantly pull attention away from its focus. This experience is not restricted to meditation practice. In our normal daily activities—while reading, for instance—we may suddenly notice that instead of being focused on the task at hand, we are focusing on unrelated thoughts and feelings (Schooler, Reichle, & Halpern, 2004). These attentional drifts are termed "mind-wandering episodes" (Smallwood & Schooler, 2006), during which attention transiently focuses on the flow of spontaneous thoughts, what James (1890/1983) called "the stream of consciousness." The subject is generally not aware of it when mind wandering occurs, and it is only after a certain period of time that he or she becomes aware that his or her attention has drifted. This realization is called meta-consciousness, a re-representation of conscious contents (Schooler, 2002; Smallwood, McSpadden, & Schooler, 2007). The mind-wandering phenomenon highlights two important facts: first, that the quality of focused attention is fluctuating, and, second, that we lack awareness of these fluctuations.

Practice of either focused attention or open-monitoring meditation requires one to keep track of which object attention is directed at and to bring it back to the object of focus each time it wanders away. This type of training may help someone become aware of mind-wandering episodes and help him or her stay focused on the moment-to-moment experience (Gunaratana, 2002). Mind wandering and meditation are thus two very different—if not opposite—states of consciousness. Mind wandering represents a shift in attention "away from the here and now" toward private thoughts and feelings (Smallwood, O'Connor, Sudbery, & Obonsawin, 2008), whereas the very basis of meditation is being present in "the here and now" without letting one's attention to be distracted by thoughts and feelings (Gunaratana, 2002; Lutz, Slagter, et al., 2008).

In favor of this hypothesis, Farb et al. (2007) revealed distinct fMRI neural activation patterns in control subjects with no meditation training compared to subjects who followed an 8-week open-monitoring MBSR program. Control subjects were primarily experiencing a mental narrative state, where one allows one's attention to be caught by a given train of thought, whereas meditation practitioners were aiming at experiencing moment-to-moment awareness of the self. Mental narrative led to strong activation of the mPFC, and awareness of present experiences led to decreased activation of the mPFC and increased activity in right lateral PFC and right viscero-somatic areas (Farb et al., 2007). Thus there might be two possible types of experience of the self: one—engaged during mind wandering—based on thoughts dealing with past or future experiences of the ego, and one based on the moment-to-moment experience of the self, involving awareness of sensory information from the body. This indicates that the experience of self in the present moment is dramatically different both experientially and in terms of brain activity from the experience of self as projected in the past or the future, as in mind wandering.

Meditation, Mind Wandering, and “Default Network” Brain Activity

The concept of a default mode of brain functioning at rest emerged from the consistent deactivation of a brain area network during a series of psychophysical tasks compared to resting baseline (Greicius, Krasnow, Reiss, & Menon, 2003; Raichle, MacLeod, Snyder, Powers, Gusnard, & Shulman, 2001). The brain network involved in baseline activity includes the mPFC, the dorsal part of which has been associated with self-referential and emotional mental activity (Gusnard, Akbudak, Shulman, & Raichle, 2001; Ingvar, 1985). Recently, higher activity in the same default network was found during a task with a high occurrence of mind-wandering episodes than during a task with a low occurrence of such episodes (Mason, Norton, Van Horn, Wegner, Grafton, & Macrae, 2007), which suggests that mind wandering could be the main underlying experience of the brain default network. For non-expert meditators, practicing meditation with attention focused on a particular object brings to awareness how frequent and pervasive mind-wandering events are. Sonuga-Barke and Castellanos (2007) proposed a hypothesis to explain the presence of mind-wandering events. Fluctuation in the quality of sustained attention, (i.e., the occurrence of mind-wandering events while one is focusing on a task) could be in part due to interference with the default mode of brain activity. In this model, interoceptive and exteroceptive attentional focus are slowly but continuously fluctuating at rest, so as to allow individuals to perceive the environment and process it cognitively. Engagement in a task (exteroceptive attention) first attenuates interoceptive attention, although with time, activity in interoceptive attention network components gradually returns, leading to episodes of mind wandering. Long-term effects of meditation training could be enhanced capacity to inhibit introspective spontaneous activity during sustained attention engagements through modification of large-scale neuronal network connectivity and activity (Lutz et al., 2008).

Consistent with this hypothesis, electroencephalography shows spontaneous fluctuations between two distinct and supposedly opposite modes during resting-state brain activity (Laufs et al., 2006). One of these modes is characterized by the presence of slow oscillations of 3–7 Hz (theta activity), which are associated with reduced level of vigilance. The other mode is characterized by the presence of fast oscillations of 12–30 Hz, which are usually associated with high vigilance levels. These spontaneous patterns of increased and decreased theta activity have recently been associated with periods of mind wandering and periods of concentration, respectively (Braboszcz & Delorme, 2009; Cahn, 2007). The hypothesized association between different vigilance levels and mind-wandering and meditation is also supported by EEG studies based on event-related potential analysis. These studies reveal that mind wandering is associated with a reduced capacity for processing external events, as assessed by a decrease in amplitude of the brain’s electrical response in this state (Smallwood et al., 2008), whereas meditation is associated with increased sensory information processing (Cahn & Polich, 2009; Srinivasan & Baijal, 2007). Thus, mind wandering tends to disconnect people from their environments, whereas meditation tends to sharpen their perceptions of it.

While meditation practice benefits psychological well-being, mental states with a high frequency of mind-wandering episode, such as depression or boredom, are experienced negatively. Carriere, Cheyne, and Smilek (2007) found that frequent brief lapses of attention, that is, lack of conscious awareness of one’s action, is associated with proneness to boredom and depression among students. More frequent and intense periods of mind wandering during a word-encoding task have also been linked to dysphoria (Smallwood et al., 2008). On the other hand, an open-monitoring meditation offered to students during a month of MBSR intervention reduced their psychological distress as well as their ruminative thoughts (Jain et al., 2007).

Meditation and Emotions

Regardless of the specific meditation technique, meditation leads to state and trait experiences involving a deep sense of peace and calm. In fact, achieving enduring happiness by freeing oneself from affliction is the central doctrine of Buddhism (Ekman, Davidson, Ricard, & Wallace, 2005). The fact that meditation affects the way emotions are experienced and allows for better regulation of negative and distressing feelings is in part an outcome of meditation-induced changes on body, brain, and cognitive functioning.

Emotions may be seen as a set of interrelated changes in the body in response to a real or imagined situation or stimulus. Emotions are experienced as feelings and may interrupt ongoing behavior or mental processes in to the form of an urge to engage in action (e.g., flight for fear, outburst of anger), depending on the emotion felt (Hamm, Schupp, & Weike, 2003). Emotions elicit responses and changes both in the body and in the attentional systems. Increased processing of body sensory inputs might also affect the way emotions are first perceived through somatosensory information. Increased concentration results most likely in better control of mind wandering; that is, enhanced attention and better resistance to distraction might reduce emotional reaction by reducing negative emotions’ propensity to interrupt the ongoing stream of thoughts and behavior. Changes in attentional capacities are also most likely linked to changes in brain activity, especially in the anterior areas, in which neural activity has been linked to the functioning of the autonomic and immune systems, which are known to be affected by meditation.

The Links Between Brain, Body, and Emotion

In the last 20 years, asymmetries in brain electrical activation have been linked with the way people react to emotional situations and regulate their emotions (Allen & Kline, 2004; Wheeler, Davidson, & Tomarken, 1993). In individuals who tend to react positively and let go quickly of negative emotions, the baseline electrical activity of the brain exhibits greater left-sided anterior activation than recordings of individuals who are more prone to nourishing negative emotions (for a review, see Davidson, 2004). After 6 months' practice of mindfulness and MBSR meditation, healthy participants showed enhanced left-sided prefrontal electrical activity in the alpha band after induction of both positive and negative feelings (Davidson et al., 2003). The same study found increased left-sided PFC activity to be associated with reduced anxiety and negative affect as well as increased experiences of positive affect. These results correlate with previous ones demonstrating that people with more left-sided baseline activation in the PFC have a more positive outlook on life than individuals with right-sided PFC activation (Davidson, 2000).

The relationship between positive affect and anterior brain areas activity is strongly supported, as reviewed by Craig (2005), by the anatomical connectivity between the autonomic system and anterior brain areas. Craig demonstrates clearly how the left anterior part of the brain interacts more directly with the parasympathetic system and the right anterior part interacts more directly with the sympathetic system. Activity in either of the hemispheres is thus associated with behavior and emotions in accordance with the opposite actions of these two components of the autonomous nervous system. Thus left-sided activation would correspond to more enriching emotions, that is, those eliciting positive, group-oriented behaviors, whereas right-sided activity would imply activity of the sympathetic system and thus reactions associated with negative, aversive behaviors.

Meditation and the Regulation of Emotions

During most meditation practice, practitioners are encouraged to keep a balanced, nonjudgmental state of mind. Practitioners can achieved this by experiencing feelings arising in their mind, then stay for a period of time, and later pass away. While meditating, practitioners in most meditation traditions are instructed to keep a calm, balanced mind, noticing affects with no feeling of aversion toward unpleasant emotions or feelings of desire for pleasant, enjoyable ones.

Contemporary research on emotion outlines two means through which emotion regulation may be achieved: attentional control and cognitive control (Ochsner & Gross, 2005). Attentional control involves manipulating the amount of attention that is naturally allocated to process emotional stimuli. Exercising cognitive control involves changing expectations or judgments about emotional stimuli. Both of these strategies are supposedly present in meditation, whether attention is focused away from the emotion (such as in concentrative practices) or the emotion is simply being observed (such as in contemplative mindfulness practices). Cognitive control is also achieved indirectly: as meditators gain insight into their minds and bodies, their appraisal of emotion automatically evolves. In addition, meditation may also change emotion's appraisal by changing the practitioner's beliefs about the world.

The way meditation modulates pain perception may provide a good overview of how meditation affects the process through which emotions give rise to specific feeling. Pain is defined as an "unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (International Association for the Study of Pain, 1994). Recently, pain has been described in terms of a homeostatic emotion, that is, as a feeling from the body (like thirst or hunger) that elicits a specific behavior to preserve body equilibrium (Craig, 2003).

Numbness and pain that arise from long periods of sitting without moving is a common side effect of meditation practice during retreats. Constantly changing position whenever pain arises would disturb meditation, so meditators are asked to use different strategies to cope with pain. According to Gunaratana (2001), it is best to adopt a voluntary and focused attitude of simply watching the pain—that is, experiencing the pain without identifying with it. Practitioners may also try to lessen the importance of the pain by comparing it with the pain that one experienced previously in one's own life, or pain that others are experiencing. Another strategy would be to divert the attention toward another object, such as the breath, and as a last resort to slowly stretch the muscles to see if the pain can be lessened. It is said that with practice, it takes more time for pain to arise and that it becomes less intense. This resistance to pain, which is a major component of meditation retreats, probably helps meditation practitioners cope with their own suffering in a more detached way after the retreat is over.

Treatments of chronic pain based on diverse meditation practices, such as MBSR programs (Kabat-Zinn, Lipworth, & Burney, 1985; Morone, Greco, & Weiner, 2008) and loving-kindness meditation (Carson et al., 2005), have revealed positive outcomes associated with improvement of overall quality of life. Enhanced tolerance of acute pain has also been assessed in different studies with both focused attention and open-monitoring meditation. Longitudinal study of transcendental meditation shows decreased brain activation in the thalamus, prefrontal cortex, and anterior cingulated cortex in response to acute pain (immersion of the hand in hot water) after 5 months of TM daily practice in participants who were new to meditation

(Orme-Johnson, Schneider, Son, Nidich, & Cho, 2006). This study further suggests that TM practice does not change actual pain sensations (as pain rating didn’t change pre– or post–TM practice and never significantly differed between beginners and long-term practitioners) but does reduce emotional distress associated with pain, resulting in enhanced tolerance of acute pain. Results of this last study are of particular significance, as they highlight meditation’s effects on the regulation of the distress associated with painful feelings. Thus meditation practice changed the way individuals reacted to the emotion related to pain. In fact, meditation seems to be acting at the feeling level, in the way pain sensations are experienced subjectively as emotions. One hypothesis is that meditation training that involves developing a nonjudgmental attitude leads to change in emotion representation, resulting in less body and mental disturbance.

In fact, the different forms of self-consciousness experienced during meditation (Farb et al., 2007) and the emphasis placed on equanimity and body sensations suggest that meditation leads to a different appraisal of somatic markers than the common normal state. According to the somatic marker hypothesis of Damasio (1994), emotions mark our experiences in terms of body representation, and these somatic markers are then used to evaluate new situations and experiences. Feelings are based on bodily response and precede emotions, which are viewed as mental reactions to feelings. In this framework, keeping a nonjudgmental state of mind during meditation could delay or attenuate emotional reactions to feelings.

Meditation and Brain Imaging

The regulation of emotions, especially of negative ones, has been extensively studied using brain-imaging techniques. Studies show that meditation actually affects two important areas of the brain emotion circuitry: the amygdala and the PFC. The amygdala is engaged in producing autonomic, endocrine, and somatic responses as well as directing attention toward affective stimuli that are potentially important, such as potential threats or potential sources of food (Davis & Whalen, 2001). The PFC down-regulates neural activity in the amygdala and the two areas share reciprocal connections (Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Davidson, 2002). Less body arousal and EEG brain activation has been observed in response to negative affects for yoga practitioners (Aftanas & Golosheykin, 2005). Consistent with this, when one is engaged in focused attention meditation, fMRI studies show that amygdala activity in response to emotional negative or positive sounds is decreased in long-term Tibetan expert practitioners compared to novice ones. Interestingly, the more hours participants have spent meditating in their lifetimes, the more important is the decrease in amygdala activity (Brefczynski-Lewis et al., 2007). However, fMRI studies show that when engaged in focused compassion meditation, expert meditators from the same tradition exhibited greater amygdala activation in response to emotional stimuli than novice practitioners (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008).

These seemingly opposite results suggest that meditation allows for a wider range of emotional experiences, and that these experiences can be modulated through the practice of specific meditation techniques. Greater embodiment or disembodiment of emotions can be achieved through voluntarily modulation of dedicated attentional circuits that have been intensively trained through meditation practice. Consistent with this hypothesis, subjective reports indicate that meditation seems at first to intensify the experience of positive as well as negative feelings. Then through practice, these intense feelings are accepted and might contribute to the experience of a richer internal life, as reported by meditation practitioners.

Taken together, brain-imaging results support the empirical hypothesis of meditation-induced emotion regulation and suggest that it involves brain plasticity. The regular practice of meditation affects the connections between the emotional limbic system and the neocortex in such a way that it would change the individual’s thoughts about and interpretation of negative emotions (i.e., his appraisal of his emotion).

Clinical Application of Meditation for Emotion Regulation

The beneficial effects of meditation on the appraisal of negative emotions have been observed in clinical practices. As we will see, meditation practice has been shown to reduce alexithymia—difficulty recognizing and expressing emotions associated with operative thought processes (Sifneos, 1973)—through development of emotional intelligence and insight into one’s emotional functioning (Baer, Smith, et al., 2004).

Appearance and inclusion of meditation in clinical practices is coincidental with the rise of the “third wave” of psychotherapies. The third wave accords particular importance not only to emotions but also to the context of those psychological phenomena and to their functions (S. C. Hayes, 2004). The third wave rises in response to cognitive-behavioral therapy (CBT), a pure dialectic approach that has been successful placing emotions in their proper context but remains limited because of the large number of complex protocols. Today, working with emotion regulation is the core process for approaching and curing mental disorders (Barlow, Allen, & Choate, 2004; Campbell-Sills & Barlow, 2007), and we are currently observing a unification of all cognitive-behavioral therapy protocols with the inclusion of the core concept of mindfulness (Allen, McHugh, & Barlow, 2007). Emotion regulation, even the regulation of extremely intense emotions resulting from trauma (Brillon, 2006), is realized through a three-step process: first feeling the body sensation (arousal), then identifying and labeling emotions that arise from both arousal and appraisal, and finally accepting the emotion in a nonjudgmental way. This last step of accepting one's own thoughts and cognitive traits has been developed by S. C. Hayes et al. (1999) in meditation-based acceptance and commitment therapy. Any clinical intervention should rely on theory addressing these three stages

.Here we first present the nature and function of emotions as well as a model of how they operate. We subsequently articulate our meditation intervention on this model.

The Emotion Apprehension Process: How Emotions Can Become Pathological

Simple principles about emotions must first be reviewed: emotions generate body (arousal) and thought (appraisal) responses (Frijda, 1986). Emotions may be useful for attaining a better response to a situation, even when they are negative (Hahusseau, 2006). In fact, patients with lesion in the ventro-median prefrontal cortex, the amygdala, or the insula, which are three important emotional brain areas, have difficulties with decision making (Bar-On, Tranel, et al., 2003). These lesions result in an incapacity to react appropriately to life events or in social contexts. This emotional intelligence deficit has been shown to be based in a neuronal system that is independent from the one supporting cognitive intelligence (Bar-On, Tranel, Denburg, & Bechara, 2003). Used at their best, emotions are felt, labeled, and accepted. If one step is missing in this process, emotions lose their power as a signal and become toxic for the mind and body.

The following metaphor will help us fully understand the need for each step in the emotion apprehension process and the potential danger of ignoring one of them: consider a wound in the sole of the foot that causes great pain when you walk barefoot on the sand. There are different possibilities for how to deal with this situation:

1 The pain is so intense that you take a high dose of analgesic. The medicine is effective and the pain disappears. For a few minutes after, you are careful not to walk on the wound. Then you forget about it and walk on the anaesthetized injured foot, worsening the depth and seriousness of the wound. This problem occurs because you have dissociated yourself from the pain and do not feel the wound anymore.

2 You feel the pain but haven't identified its origin. You believe it's a scratch and place a bandage on it without removing the piece of dirty broken glass lodged in the foot. The wound gets infected and worsens. This problem arises because the nature of the wound was not adequately identified.

3 You feel the pain and have identified its origin but feel scared. You refuse any examination by a doctor for fear that it will be too painful or you refuse to go to the hospital, arguing that you do not have time. The wound gets infected and you are immobilized for a long period of time. This problem arises because you did not accept the wound.

The types of possible reaction we considered for a physical wound are also present for negative emotions. If one does not feel one's emotions (i.e., dissociative disorder), does not identify them (i.e., alexithymia), or does not accept them (i.e., emotion intolerance), analgesic effects can provide short-term relief, but mental and physical health are affected over the long term.

The Three Majors Emotional Disorders

Each of the three following emotional regulation disorders corresponds to an anomaly or blockage in the process of the emotion arising, developing, being experienced, and eventually vanishing. They are at the origin of most mental disorders and very often are intertwined. Taking them into account is thus of primary importance in therapeutic approaches.

Dissociative Disorder

The absorption experience, experienced by 80% of people when reading or watching a movie, and different forms of dissociative disorder as described in *DSM-IV-TR* (DSM IV, American Psychiatric Association, 2000) have common characteristics: the narrowing of both consciousness and perceptual fields. In its most spectacular form, it can result in multiple personality disorder or dissociative fugue. "Dissociation is a process where the usually integrated functions of consciousness, memory, identity or perception of the environment are spontaneously disrupted and certain mental events that are ordinarily processed together (e.g., thoughts, emotions, sensations, etc.) are isolated from one another" (American Psychiatric Association, 2000, p. 167).

Dissociative patients commonly have particular difficulty adapting to new situations and to establish daily routines such as choosing a regular schedule for eating or sleeping. They are poorly connected to their internal sensations and barely feel pain and other body sensations, such as their heartbeat or breathing. Dissociative patients don't adapt to day-to-day reality; they don't pay attention to directions when going from one place to another and listen to but don't comprehend conversations. There are people and objects in their homes that they know or have seen but don't remember. In general, they have few memories, even of important life events, and they doubt the veracity of those memories they do have. These persons live exclusively in the mind; they do not have feeling of themselves and are unable to focus on the present moment. If placed on a continuum, dissociative disorder and mindfulness would be at opposite ends, mindfulness being the capacity to be aware of the moment-to-moment unfolding experience while keeping a nonjudgmental attitude (Kabat-Zinn, 2004).

Dissociative disorder affects about 10% of the population (Foote, Smolin, Kaplan, & Legatt, & Lipschitz, 2006; Ross, 1991). Dissociative disorder is often associated with difficulties controlling impulsivity, chronic pain syndrome, and fibromyalgia. It is also preponderant in patients suffering from mental disorders such as depression, anxiety disorder, addiction, anorexia, and binge eating (Valdiserri & Kihlstrom, 1995) as well as personality disorders. The most frequently associated comorbidities include borderline personality disorder and post-traumatic stress disorder (Dell, 1998).

Alexithymia

Difficulty identifying emotion, which is characteristic of alexithymia, comes from the inability to express emotions to others (Taylor, 1984). Alexithymic patients tend to be inexpressive and emotionally "restricted" and have difficulties bonding with others (Taylor, 2000). The occurrence of separation and divorce is higher in this population than in the normal population. Alexithymia as evaluated with the 20-items Toronto Alexithymia Scale (Bagby, Taylor, & Parker, 1994) affects about 15% of the general population with a slight over-representation of men.

This disorder is often associated with personality disorders, addiction to substances such as alcohol, toxics, and sedatives and eating disorders like binge eating. It is also often associated with somatic disorders (arterial hypertension, anger, asthma, etc.).

Emotional Avoidance

Even when they are suited to life circumstances, negative emotions (sadness, fear, shame, anger, stress) may generate stress if one does not feel one has control over them. They may also generate fear (that they will never end) or shame (at the idea that one is the only person to whom this happens). In these cases it is not one but two emotions that distress the mind and body (Greenberg, 2002). In a sense, it becomes twice as hard to cope with emotions (see figure 27.2). Thus negative emotions like sadness and anger that should be restricted in time turn into long-lasting negative moods such as depression or sustained resentment. Since negative emotions are often experienced as pain in the body, secondary emotions (Greenberg & Paivio, 1997) might lead to the development of chronic pain.

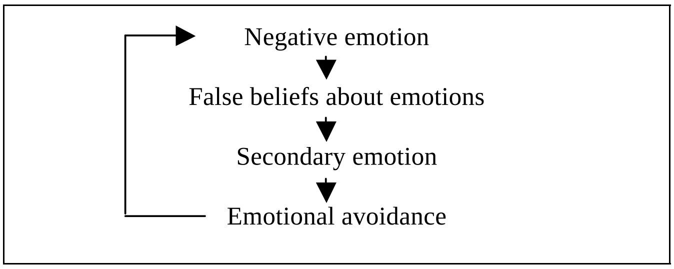

Figure 2. Emotional intolerance model

Patients who experience emotional avoidance can have four types of fearful ruminating thoughts: (1) fear that the emotion will never end; (2) fear that the emotion will lead to loss of control over behavior; (3) fear of other people's judgments; (4) the fear that intense body arousal that results from the emotion could be a major disease (Williams, Chambless, & Ahrens, 1994). When an emotion is perceived as bearable and is accepted, no conscious effort is made to suppress it, and mood stabilizes spontaneously. Conversely, efforts to suppress emotions exacerbate them and are at the core of most mental disorders.

Since this disorder has only been recently identified, there is no real estimation of its frequency of occurrence in the general population, although Barlow argues that it is responsible for most mental disorders (Barlow et al., 2004).

Meditation-Based Emotion Regulation

The new meditation-based approach to emotional dysfunction emphasizes the advantages of the development of body perception of emotion, then identification and acceptance through meditation (S. C. Hayes, 2004). Thus, for example, in moving meditation such as yoga, what seems to be efficient in regulating emotion is self-observation, concentration, and acceptance; during this process attention is placed on sensations, and impermanence acts as a background mind-set (Campbell & Moore, 2004). Talk therapy (purely intellectual therapy) seems more limited.. "The absence of direct connections from the PFR-L to the amygdala may be related to why talk therapy for psychiatric conditions that involve amygdala-related conditions is relatively inefficient (in terms of the amount of time required to achieve a therapeutic effect)" (LeDoux, 2002, p.292).

Meditating is thus a way to deal with dissociative disorders through the development of a mindful attitude. It is also a way to deal with alexithymia in that it helps patients increase emotional intelligence and enhance their emotional tolerance through exposure to emotions. Different types of thoughts suppression in all mental disorders are causal factors in long term increase of emotional arousals and appraisals (Levitt, Brown, Orsillo, & Barlow, 2004). Meditation thus can be used to prevent the use of avoidance strategies, which involve physiological arousal (interoceptive) avoidance and cognitive avoidance (use of other thoughts as distraction), procrastination and worrying (avoiding emotionally salient tasks) and rumination in depression (Nolen-Hoeksema, 2000).

Meditation-Based Protocols and Depression

Medication-based therapy as well as psychotherapies (cognitive therapy and interpersonal therapy) are successful in curing punctual depressive episodes but fail to prevent relapses. After three major depressive episodes, the probability of relapse is about 90%. In addition, the continued use of antidepressant over several years may be problematic because of the presence of side effects and addiction issues. Finding alternative treatments has become critical, especially since the World Health Organization predicts that in 2020 depression will be the ranked second most common illness worldwide. Meditation-based clinical intervention can help tackle this major health care issue.

About 40 studies have shown that, once treated with a meditation-based protocol, patients do not differ from subjects without depressive history in regard to the amount of negative thoughts they have (Ingram, Miranda, & Segal, 1998). Instead of studying thoughts' effects on mood, some researchers have also studied mood's effects on thoughts. For example, Teasdale (1983, 1988) showed that experience-induced sadness (induced by sad music or sad reading material) had more impact on subjects with a history of depression than on control subjects (Segal & Ingram, 1994). Negative emotions thus seem to have a more lasting effect in subjects who have suffered from depression. Reactivation of negative thoughts in these subjects preserves and deepens sad moods through a series of vicious cycles. Sad moods can thus generate lasting negative thoughts to the point that a slight mood impairment for these patients can trigger disastrous changes in thought patterns and can be responsible for of the persistence of depression and relapses.

Cognitive reactivity describes the ability of a slight change in mood to degenerate into a series of deeply negative thoughts. Cognitive reactivity has a cumulative impact: each depressive episode increases the probability of a new one since, with time, the depression circuitry is more readily activated. Early depressive episodes are most often preceded by significant negative events but as new episodes occur, the role played by these events becomes less clear. Each new episode seems to lower the threshold for depression onset. With time, this threshold tends to get so low that depressive episodes seem to occur spontaneously. Even when an episode of depression is over, cognitive reactivity remains and puts the patient at risk of suffering another episode. Changing a person's relationship with his or her own thoughts and negative emotions—in a way that doesn't directly act on the content of thoughts—is key to stopping the vicious cycle of cognitive reactivity.

Jon Kabat-Zinn relied on mindfulness-based practices to put distance between the patient and his cognitive, emotional, and sensory experiences (Kabat-Zinn, Lipworth, Burney, & Sellers, 1986; Kabat-Zinn et al., 1992). Kabat-Zinn's mindfulness-based stress reduction program has become widely popular since about 1970 and is now often accepted in clinical settings. MBSR is a structured group program composed of 8 two-hour weekly sessions. Sessions are centered on mindfulness practice (simple Zen-like mindfulness meditation) and experiential feedback. Participants commit to practice at home for 45 minutes daily, at least 6 days a week. MBSR has been shown to be efficient for stress reduction (Davidson et al., 2003). Mindfulness-based cognitive therapy (MBCT) is largely based on Kabat-Zinn's stress reduction program and has the same format as MBSR except that it makes use of cognitive therapy in addition to meditation (McQuaid & Carmona, 2004). MBCT therapy has proved to be efficient, as it reduced the probability of relapse by about half among patients who had experienced at least three major depressive episodes (Michalak, Heidenreich, Meibert, & Schulte, 2008; Teasdale, Segal, Williams, Ridgeway, Soulsby, & Lau, 2000).

Here is how Kabat-Zinn (1990) describes the emotional detachment process: "It is remarkable how liberating it feels to be able to see that your thoughts are just thoughts and that they are not "you" or "reality"... The simple act of recognizing your thoughts as thoughts can free you from the distorted reality they often create and allow for more clearsightedness and a greater sense of manageability in your life . Mindfulness thus provides a method for detachment that turns into recognizable changes in mood. Kabat-Zinn's mindfulness does not teach people how to avoid unpleasant emotions and life events: it only proposes to teach people how to live with them.

Thus asking patients to perform a particular task (i.e., meditation) when negative thoughts cross their mind may help them to abstain from totally identifying with these thoughts. It automatically puts some distance between the patient and his or her negative thought-affect and allows the patient to tolerate these thoughts better. It also absorbs the patient's focus of attention and the limited information-processing resources of the brain, thus allowing the patient to avoid the ruminative loops of thought-affect. Eye movement desensitization and reprocessing (Shapiro, 1999), a technique that involves performing repetitive eye movement while recalling traumatic events, most likely works on the same principle, although it lacks the emotional intelligence component that is characteristic of meditation-based interventions.

Meditation-Based Emotion Exposure

Meditation protocols are powerful clinical interventions and should not be taken lightly. For instance, some form of concentrative meditative practices could lead to emotional avoidance, as they instruct practitioners to direct their attention to a specific object while ignoring all others, including negative thought-affect. They could thus train patients to avoid negative thought affect, leading to with potentially significant consequences.

MBSR and MBCT are suitable to use to prevent relapses in depression but require adjustments when applied to intense negative emotions in patients with emotional trauma. The procedure used in these practices could lead to a form of emotional avoidance, as the attention is intentionally and plainly redirected toward specific emotional material. Below, we provide an adaptation of these practices that relies on breath awareness meditation (a basic form of meditation inspired from Zen and Vipassana), which is less abstract and easier to achieve than mindfulness for beginners.

The meditation-based emotion exposure (MBEE) protocol has been described by Hahusseau as grouping together all elements of the emotional psychosomatic process. It is mostly inspired by MBSR and MBCT. However, MBCT and MBSR involve standard meditation followed by cognitive assessment. In contrast, MBEE, like acceptance cognitive therapy and eye movement desensitization and reprocessing, places the emotion at the center of the meditation practice.

1. Chose a target emotion and assess the discomfort it creates here and now on a scale of 1– 10. It can be:
   –A pervasive negative emotion
   –A painful sensation
   –The image of a recurrent memory
   –An intrusive and compulsive thought or belief
   –A worry
2. Put yourself in respiratory sinusal arrhythmia by
   a. Isolating yourself
   b. Closing your eyes
   c. Placing your attention around the nostrils, the ribs, or the abdomen without trying to slow down or change your breathing, but simply observing your breath and breathing sensations
   d. Trying to feel both your cardiac rhythm and respiratory movements in the same areas of the body.
3. Use the following guidelines to expose yourself to emotions for at least 30 minutes while keeping the eyes closed. The only goal here is to follow your attention and to be aware of where it goes, while remaining aware of the breath. Whatever thought arises in your mind or sensation in your body, simply observe it, without judgment, and with the kindest and most compassionate attitude possible (Lutz et al., 2004; Neff, 2004), without any desire to change it or to ease the pain, simply following the breath until the breathing cycle is complete.
   a. Intentionally direct your attention toward the target emotion until your attention becomes attracted by another thought, emotion, or object.
   b. Observe, without any judgment, where your attention is being drawn.
   c. It is possible that you might experience a physical sensation. In this case, follow the breath toward this sensation, not trying to stop or resist it, but simply trying to feel it. If it is painful, simply observe how much pain you feel.
   d. If your attention is attracted by some mental content—a thought, a memory, a worry, a question—observe this content as if it were written on a screen and at the same time feel what happens in the body. What bodily sensation is present? Observe how much this thought and its associated feeling proves that you are suffering now. Try to label the emotion you are experiencing (sadness, anxiety, anger) and stay in touch with it.
   e. If you realize your attention is lost in other thoughts, begin again, using the initial target emotion.
4. After emotion exposure:
   a. Assess again the discomfort you feel on a scale of 1–10.
   b. Briefly write down what you observed during the exercise.
   c. In the following hours, observe if anything has changed since before the exercise.

Clinical Application of the MBEE to Binge Eating Disorder

Following a failure of classic behavioral therapy with a patient suffering from an eating disorder, Hahusseau tested the meditation-based emotion exposure protocol described above. The literature shows that 20%–50% of patients with eating disorders have a traumatic history, such as sexual abuse during childhood. Traumatic history is neither sufficient nor necessary for an individual to develop an eating disorder. However, it is known that a combination of abuses, such as an unfavorable family environment (Vanderlinden & Vandereycken, 1997), significantly increases the probability of binge eating (Hastings & Kern, 1994).

It is hard for eating disorder patients with traumatic histories to regulate their emotions (Van der Kolk, Pelcovitz, Roth, Mandel, McFarlane, & Herman, 1998). Self-mutilation and addiction to benzodiazepine or alcohol are found in 70% of eating disorder patients with a traumatic history, but in only 15% of eating disorder patients without a traumatic history (Gleaves & Eberenz, 1994). The frequent combination of abuse (Barker-Collo, 2001), dissociative disorder (Maaranen, Tanskanen, Haatainen, Koivumaa-Honkanen, Hintikka, & Viinamaki, 2004), and eating disorders (L. Brown, Russell, Thornton, & Dunn, 1999) eventually led Hahusseau to offer her patients MBEE.

Here we describe two case studies that illustrate use of the protocol and demonstrate its potential efficacy. Some studies have already started investigating the benefits of meditation for eating disorders, particularly for binge eating disorder (Kristeller & Hallett, 1999), and protocols were judged to be "most likely efficient treatments" (Baer, 2003, p. 129). MBEE involves first collecting anamnestic data (patient history), then training the patient to perform the emotion exposure protocol and guiding him or her through it. The protocol has been split in two sequences: past-emotion exposure sessions are done at the therapist's office and current-emotion exposure sessions are done twice with the therapist, then at home by the patient on his or her own.

Françoise

Françoise was married with two kids. She was 52 years old and 5 feet 7 inches and weighed 233.2 lbs for 20 years. Françoise was a nurse and had a history of postpartum depression. She wished to see a therapist for binge eating disorder and her uneasiness at work. She had already done two 8-year-long psychotherapies. Her weight anamnesis revealed that her father called women "fatty" and she gained considerable weight after her children's birth. She snacked excessively and was not physically active. At work she felt insecure during planning discussions, and she always agreed to do the most demanding tasks. Her colleagues disliked her and saw her as too obsequious. She was aware that her fear of her colleagues’ criticism was unreasonable and that her behavior was not appropriate but she did not seem to be capable of changing it. She did not dare say "no"..

The primary therapeutic hypothesis was the following:

- Her social situation leads to negative emotions.
- Negative emotions lead to assertion disorder and submission.
- Assertion disorder and submission lead to dissatisfaction.
- Dissatisfaction leads to snacking.
- Snacking leads to more negative emotions.

The therapeutic plan initially consisted of the behavioral exercise of positive self-assertion (Stravinsky, Marks, & Yule, 1982). Although she was motivated to complete the assignments and was consistent in doing so, the first 30 sessions did not provide satisfying results. She failed to successfully assert herself and her intense negative emotions remained unchanged. She still could not express herself at work. No weight change was observed during this initial therapeutic approach.

She then tried MBEE. The chosen past emotion related to her father beating her brother in front of the whole family. Françoise experienced repetitive traumatic reliving of scenes between her father and brother. As the youngest child in her family, she had felt neglected growing up. Her mother’s submissiveness and father’s inflexibility and violent fits also added to her feelings of insecurity. As a child, her primary emotion (Damasio, 1994) or behavioral tendency (Frijda, 1986) was passive submission. Since then she had suffered from dissociative disorder.

Recalling the violent scenes between her brother and father produced anxiety, extreme insecurity and helplessness, and feelings of guilt, sadness, and anger. During the emotion exposure protocol, her somatic response was severe and involved abdominal pain and accelerated breathing rate. She rated her reaction as 7 on a 1–10 subjective intensity scale. The emotion exposure protocol allowed her to release these intense emotions and other emotions associated with traumatic memories, such as her sexual molestation by a doctor, her father’s insults when she was 18 years old, and eventually her brother’s suicide. The total exposure consisted of 30 session of 1 hour each with two sessions devoted to learning the protocol so she could practice emotion exposure at home on her day-to-day experiences.

Within a year Françoise lost about 66 lbs; she is now involved in sports and is happy to feel her body again. At work she is now at times assertive, expresses her feelings, and no longer runs away from conflict. She is now more accepting of herself. Today, after 3 years, she still weights 167 lbs.

Anabelle

Anabelle was a 45-year-old seamstress. She was 5 feet 3 inches tall and weighed 211 lbs. She wanted to consult a psychiatrist for problems in her relationship and for her eating disorder (for which she is also considering gastric bypass surgery). She and her twin brother were the youngest in a family of six children. Her mother had been diagnosed with psychosis. Anabelle was divorced with two children ages 20 and 24. She had been in treatment for 5 years and regularly used benzodiazepines to ease her anxiety. Her treatment at the onset of the emotion exposure protocol was Seltraline-50 once a day and 10 drops of haloperidol. Her eating disorder had begun a year prior to her divorce, when she was 32. Her weight had increased ever since, and her behavior reflected her shame: she would closes the door of her home quickly so the neighbors would not see she was overweight. She had one eating crisis per day, she seemed to be emotionally unresponsive, and her colleagues at work rejected her. She had had a difficult childhood and was often kept awake by her psychotic mother’s scream at night. She and her siblings regularly experienced violent attacks by her father. At 10 years old, she was sexually abused by her brother-in-law and, as a result, suffered from dissociative disorder. When she recalled this traumatic event, she rated it as 6 on a 1–10 pain scale.

Anabelle attended a total of 20 sessions: 10 sessions of 30 minutes for data collection and functional analysis, then nine 1-hour sessions dedicated to MBEE targeting the traumatic event, and finally a 2-hour session dedicated to learning the technique so she could learn it at home on her day-to-day emotions. After the second emotion exposure session, Anabelle started to lose weight without effort.

She now weights 172 lbs and has changed her mind about having gastric bypass surgery. She regulates her emotions by crying. She once again feels her body, can experience satiety, and believes she is making progress addressing her dissociative disorder. She decided to stop taking antidepressants during the emotion exposure treatment. Today, after 6 months, she has not regained weight.

Toward Objective Marker of Emotion Exposure

Emotion regulation describes an individual’s capacity to adjust from a high arousal level produced by sympathetic nervous system activity to a less elevated one, which depends on the parasympathetic autonomic nervous system (Gross, 1998). Some measures of autonomic system activity such as heart-rate variability (HRV) can thus be used to assess emotion regulation. As we have seen, one primary effect of meditation is to spontaneously activate the parasympathetic system. Systematic observation of patients’ HRV recordings during the MBEE revealed that each of its steps (feeling, labeling, compassionate acceptance) influenced the 2- to 3-second cycle sinusoid component of heart-rate variability. In the meditation-based emotion exposure protocol, the unique instruction given to the patient is to observe without judgment—and while breathing—his or her emotional, cognitive, imaginary, sensorial material.

Various meditation practices have been reported to induce an overall increase in HRV (Bernardi et al., 2001; Cysarz & Bussing, 2005; Ditto et al., 2006; Lehrer et al., 1999; Phongsuphap, Pongsupap, Chandanamattha, & Lursinsap, 2007; Takahashi et al., 2005), which is most often interpreted as an increase in parasympathetic over sympathetic activation. The protocol could help suppress cortical influences on the sinusal node that could disturb the heart's autonomic regulation (Craig, 2005); however, tasks that involve changes in respiratory rates must be carefully analyzed to avoid flaws in HRV interpretation (Grossman & Taylor, 2007). Furthermore, in dissociative disorder patients, it is possible to observe in the HRV time series a decrease in activity of the autonomic nervous system, as shown by a study of skin conductance measure (Sierra et al., 2002). HRV would then reflect activity from efferences of the central autonomic network (Thayer & Lane, 2000) and could be used to measure the presence of voluntary control over emotions, called avoidance, or its absence, called acceptance.

Though further study is necessary before a link can be made between meditation-induced increase of the HRV and emotion regulation, preliminary results suggest that HRV could be used as both an emotional exposure marker and a meditative state marker. A better understanding of the origin of HRV changes during different meditation practices may help us understand the mechanisms behind meditation-based emotion regulation.

Conclusion

Meditation promotes both physical and mental well-being and contributes to the development of positive emotional traits (K. W. Brown & Ryan, 2003). It is thus important to integrate its active principles in therapies for patients suffering from physical diseases and mental disorders (Bishop et al., 2004). Becoming aware of the fluctuating quality of thoughts, sensations, emotions, and other internal phenomena helps reduce dissociative disorders and the perceptual narrowing that these disorders induce. It also helps reduce alexithymia and emotion avoidance, in which a large number of psychiatric disorders are rooted.

As we have seen, meditation-based interventions such as mindfulness-based stress reduction and mindfulness-based cognitive therapy are already being used in depression relapse prevention programs. These techniques have also been modified and adapted for the treatment of acute disorders such as chronic pain, depression, fibromyalgia, and psoriasis, as well as anxiety, eating, and psychosomatic disorders. In all cases, results have been encouraging and support its use in therapeutic practices (Baer, 2003). In the years to come, we hope to see the development and validation of more meditation protocols adapted to specific disorders.

In the case of eating disorders, the disorder can sometimes be simplified and regarded as resulting from a traumatic emotional experience. Under genetic predisposition and in the context of an adverse social or familial environment, eating disorders foster complete avoidance of negative emotions. Thus, as current negative emotions are instinctively avoided due to early traumatic experiences, eating crises appear to be a preferred mode of emotional shunning. Emotional dissociative disorder and binge eating disorder appear to have identical functions: to suppress the natural emotional process (feeling, labeling, accepting; Hallings-Pott, Waller, Watson, & Scragg, 2005). HRV during MBEE session turns out to be an excellent index of emotion regulation capacity, which is the capacity to feel, label, and accept emotions. The combination of high levels of respiratory sinusal arrhythmia achieved during meditation, enhanced emotional regulation, and the use of more suitable coping strategies has proved useful for weight loss (Fabes & Eisenberg, 1997).

The diverse effects of meditation on the body and cognitive and affective processes are beginning to be understood, and these techniques are now used in clinical settings for patients suffering from emotional and attentional disorders. The wide range of observable effects of attentional training during meditation allows us to study the multiple connections between the mind, brain, and body. Such connections are increasingly being acknowledged, and their investigation offers new pioneering approaches both in clinical practices and in fundamental cognitive neuroscience research.

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Chapter 9

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