Contemplations into respiration: effects of breathing and meditative movement on body and mind

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Chapter 1

General introduction

Cognitive psychology studies fundamental functions and processes of the human mind; functions such as: perception, attention, memory, emotion, decision making, and language. It traditionally proposes mechanisms for these *cognitive functions* and captures their dynamics into *mental models*. These models are inspired, informed, and validated in empirical studies using (computerized) tasks. In these experiments, conditions are contrasted where these cognitive functions are assumed to be differentially affected. The conditions then should differ in how accurate or fast participants perform the tasks, or steps therein. Notably, measures of *reaction time* are taken to elucidate cognitive processes. Mental chronometry (Donders, 1868) is a research paradigm that harks back to the finding that nerve pulses travelling through the body take time (Helmholtz, 1850). Recently, cognitive psychology has crossed over with neuroscience into the field of *cognitive neuroscience*, which attempts to couple cognitive models to brain anatomy and function.

Contemporary cognitive psychology is highly influenced by the metaphor of the human mind as an information processing machine: a computer (Fodor, 1968, 1975; Putnam, 1967, 1975). In this view cognition is *computation*. Also, in classic cognitive science — and classic artificial intelligence — there is believed to be a *central executive system* (Baddeley & Hitch, 1974), that makes decisions and directs the body top-down. In terms of the computational view this could be seen as both the processor and RAM-memory — working memory — of the information processing system. The executive system hierarchically controls how the information is processed. For a full review of the classic cognitivist view, see Dawson (2022). However, from the 1990s onwards a competing view to the computational conception has arisen: embodied cognition (Lakoff & Johnson, 1999; Varela et al., 1991).

Embodied cognition

In contrast to the classic computational approach, contemporary embodied cognition (Anderson, 2003) rejects that cognition solely happens in the brain, in isolation of the rest of the body and the outside world. In other words, humans are not simply run by a computer contained in their skulls. Next to the brain, the periphery and viscera of the body proper play an active, causal and critical part in cognition. In the embodied view there is no single central executive that directs all action top-down. The state of the body and its actions also influence cognition bottom-up. See Shapiro (2021) for a complete introduction to the embodied field. Three pioneers of the embodied mind need introduction for a better understanding of this work.

If we try to go back to the earliest form of any psychological theory then we usually end up at William James (1842-1910). For the embodied mind perspective, this is no different. In the *Principles of psychology* James (1890) pertains that the experience of an emotion is merely the mind's sensation of a bodily state. This view might now be described as belonging to the extremist stance of embodied cognition. Herein the causal relationship between body and brain is unidirectional, bottom-up — from the body towards the brain. Modern proponents of the embodied mind generally view this relation as being bidirectional; both bottom-up and top-down.

Clark (1997) — in his seminal book *Being there* — describes how the brain, the body and the environment are equal parties in producing effective action. The mind is not contained but extended: it also inhabits the body (and the environment). Cognition is not passive computation, but it is active and evolves in dynamic interaction with the environment. Cognition is rooted in the physical experience of reality (i.e. the body and the world) and operates in real time. Indeed, in many contexts *decentralized solutions,* solutions that rely on a close-coupled dynamic interaction between body and environment produce better adapted behavior and optimized performance than does centralized control; behavior as directed by a central executive or central nervous system. Very loosely summarized: doing trumps thinking.

Damasio (1999) makes the argument on neurological grounds — in his canonical work *the feeling of what happens* — that the body is central in constructing conscious awareness and the psychological self. The fundamental tenet of the claims in this work is the *somatic marker* hypothesis (Damasio, et al., 1996), which states that there is no cognition without emotion. All (higher) processing in the brain is stamped by emotion, which gives thoughts their value and valence. Furthermore, goal-directed behavior without these emotional stamps is impossible. An individual would simply have no way of choosing a course of action; appropriate, preferred or otherwise. Similar to James (1890) this emotion starts in the body: the somatic part of the marker. Though the brain is able to create bodily states — through neural and hormonal pathways — it is also constantly itself being informed and influenced by these states, by the internal milieu (Bernard, 1865). For example, biomarkers on cardiopulmonary functioning, such as blood pressure and CO_2 blood levels, are constantly being monitored in the brainstem, sent upstream and change central functioning. In rats the vagus nerve not only monitors norepinephrine and epinephrine levels, but enhances memory function through projections to the forebrain (Williams & McGaugh, 1992, 1993). This bidirectional relationship is what Damasio calls the *body loop*. The brain influences the body, which returns feedback, changing brain states and leading to downstream adjustments, and so the cycle continues. Succinctly summarized: body states change brain states.

Let me give a concrete example of such bottom-up influences: the facial feedback hypothesis (Strack et al., 1988). According to this hypothesis facial muscles responsible for certain emotional expressions, can actually produce or inhibit these emotions themselves by being mechanically stimulated, or inversely by being impeded to contract. In the original study this was done by participants holding a pencil in their mouths, which makes muscle groups contraction and relaxation for certain emotional expressions impossible. The facial feedback hypothesis also maintains that manipulating expression influences cognitive processing higher up, such as in social recognition. Havas and colleagues (2010) showed in their infamous Botox study that paralyzing the specific muscles to an emotion like happiness, also hampers the recognition of this emotion in others. Thus, here we have an example of a peripheral cause not only directly influencing emotion, but also cognition. However, a slight disclaimer is in order on the facial feedback hypothesis. In a replication study by Wagenmakers et al. (2016) of the original study of Strack et al. (1988) the original results could not be replicated. Then again, a recent meta-analysis (Coles et al., 2019) has concluded that the facial feedback effect does exist, albeit small and heterogeneously produced.

It may be clear by now, that the current work is situated in the embodied corner of the debate. However, there is another trend in cognitive neuroscience that is of paramount importance to this work. Cognitive science has also branched out into an applied field. There cognitive enhancement is a main goal: leveraging the plasticity of the brain to improve cognitive functioning.

Cognitive enhancement

First, we need to make a critical distinction between the aforementioned *central executive system* and *executive functioning*, also known as *cognitive control* (Hammond & Summers, 1972). The first is a central component of a cognitive model that directs behavior like a little puppet master in the head, the latter are several distinct processes, that among others help steer behavior away from ingrained patterns and trodden tracks, inhibits socially inappropriate behavior, is necessary for doing tasks consisting of multiple serial and parallel steps (like following a recipe), manages working memory, and readapts strategies to new behavioral goals. In contrast to the central executive these executive functions are only cogs in a vastly complex machine, not their centerpiece (Miller, 2000). In other words: the first one's existence is in serious doubt, the second is clearly established. The existence of these control processes are easily made apparent when they fail. For example in attentional capture: paying attention to salient stimuli that are irrelevant in the current context; and in perseverance: continuing with prepotent behavior that has become inadaptive or even dysfunctional (Monsell, 1996). Everyone knows the experience of being distracted by a prompt on your phone. Only to find yourself back in the present moment, having run the social media rabbit hole, that message led to and are left wondering what that very important thing was, you were in the middle of doing. This is a classic failure of cognitive control. Summarizing: executive functioning is something different from the central executive. This is relevant here because many cognitive enhancement attempts are oriented towards these functions, as are ours.

Cognitive enhancement (Juengst, 1998) — in the broad sense — has as its aim to improve any form of mental functioning by any means possible, such as improving mental health, language ability, social cognition in group dynamics. This can be achieved by means of computer training, physical exercise, diet, or even drugs. These all fall under the umbrella term cognitive enhancement. The means to this cognitive end can be categorized into three domains: pharmacological, physical, and behavioral (Dresler et al., 2018). See Marois and Lafond (2022) for a review of these different enhancement applications. In this work we will be concerned with the enhancement of fundamental cognitive functions, such as attentional and cognitive control, by the least invasive domain of intervention: the behavioral (Green et al., 2019).

Behavioral cognitive enhancement can take many forms. Some could be described as physically inactive, such as: gaming, training, language learning; some as active: physical exercise and mind-body exercises. As our focus on embodied cognition suggests, this work uses a family of applications that aims to intervene on both mind and body, though the way of change lies from the body towards the mind and back again (Kerr et al., 2013). These are the traditions of contemplation.

Contemplative practices

Contemplative activities come in many forms, the shape of which is usually passed down from (Buddhist) religious practices. Just the contemporary popular styles of meditation are myriad. To name a few: Vipassana, Transcendental, Zen, Compassion, and Loving-Kindness meditation. Then there are the meditative traditions that also include some form of physical exercise, like moving slowly and continuously or smoothly from stationary posture to posture. These mind-body exercises include practices such as: tai chi chuan, qi gong, walking meditation, and – with its diverse styles and by far the most widely practiced of all: yoga. For a systematic categorization of meditation practices see Lutz et al. (2017) and Matko and Sedlmeier (2019).

Varied as these practices may be, they do have a common thread: the meditative or contemplative aspect, commonly called *mindfulness*. The famous Vietnamese Zen Buddhist monk Thich Nhat Hahn, who passed away earlier in this year of writing 2022, describes mindfulness as: to pay attention to something, to remember being in the here and now, but also: to not judge in the present moment (Hahn, 1997). This attention in the present moment is key. It offers what to be mindfully attentive of. This attention can vary in its scope. This is where it diverges from the cognitive psychological construct of attention. In the work of Lutz and colleagues (2008) a division is made between focused attention meditation and open monitoring meditation, as a broad stroke dichotomy where most practices can be categorized. In focused attention meditation, attention is like the spotlight in psychological theory. It illuminates a single sensation, that can jump – like a saccade – from object to object in the visual field. For example, a practitioner might focus on a single part of their body, redirecting their attention back to it, gently, whenever distracted. In contrast, practicing open monitoring meditation means letting in awareness of any sensation, of any sensory modality (e.g., hearing, smell, pain), or thought or emotion, that comes to mind. Practitioners attempt only to pay attention to these sensations fleetingly, to not dwell, before moving on to the next draw. It is believed that, through extended practice and experience, awareness can be spread and distributed across all sensory modalities and feelings in in a singular moment. It turns out that training attention in these divergent ways matters: it affects attentional functioning longitudinally in the trained direction. In another study by Lutz and colleagues (2009) practitioners increased the stability of their (auditive) attention both behaviorally and neurally (EEG), after following a three-month training in focused attention meditation. However, a recent study showed that short bouts of meditation in either focused or open meditation had no effect on attentional function and this seemed to be explained by individual differences in mindfulness traits (Tanaka et al., 2021).

Whatever the scope of attention might be in any given exercise, one family of sensations in focus is always present: the bodily. In the body scan one goes through the whole body while sitting or lying down. Qi gong emphasizes proprioception, while moving slowly and with attention. During sitting meditation (like Samadhi) one looks for the feeling tone – the dominant mood or affective state – and is thus more preoccupied with interoception — emotional body feedback; as both positive or negative affect has biological markers that can be picked up by body awareness exercises. Whatever the focus of the particular practice, mindfulness starts in the body (Kerr et al., 2013). Within the practices that train awareness of the body, a special role is reserved for the sensations of respiration. Furthermore, respiratory patterns are also actively modulated in practice.

Breathing exercises

Contemplative activities frequently take breathing as the focus of awareness in their instructions. It is thus reasonable to assume that this will affect respiratory patterns and biomechanics. Furthermore, many contemplative traditions actively prescribe breathing exercises. Actively controlled breathing seems to have different neural routes than do autonomic respiratory drives, as in rats between respiration in fight-or-flight mode and when vocalizing (Subramanian et al., 2001). Breathing control in humans has been theorized to be the necessary evolution for human speech to be possible and indeed the respiratory innervation of the thorax in humans is comparatively increased with other primates (Lieberman, 1991).

The instructed respiratory patterns in contemplative breathing exercises vary in respiration rate, durations of inhalation versus exhalation, breath-holding, and locus of breathing (the location of intentionally directed muscles groups). Though these instructions vary, the vast majority of exercises does show a clear common thread: towards slower breathing, shifting to an abdominal locus and sometimes with extended expiration. Research into the effect of a lower respiration rates on autonomic nervous system activity has indicated an optimal rate of 6 breaths-per-minute (or lower) for increased relaxation (van Diest et al., 2014). This is reflected in a lower mean heart rate, blood pressure (but with more fluctuations and cardiac synchrony) and variability in heart rate (Russo et al., 2017). This suggests that specific respiratory patters do not only reduce stress, but also increase systemic flexibility.

Systemic flexibility

Heart rate variability (HRV) is a metric that quantifies the moment-to-moment fluctuations in heart rate. The time interval between heart beats is never the same. The more this interval varies across a given period, the higher the HRV score, whereas less variation means a lower HRV score. Thus, two individuals might have the exact same heart rate – the average number of heart beats per minute – but may differ widely in its variability.

HRV is a useful indicator of individual cardiovascular health and overall physical condition (Singh et al., 2018). The higher resting state HRV, the better the cardiopulmonary condition is. Furthermore, HRV is a valid indicator of stress levels, both acute and chronic (Kim et al., 2017). This is because variations in heart rate are differentially produced by the branches of the autonomic nervous system: parasympathetic activity increases HRV, while sympathetic activity decreases HRV (Singh et al., 2018). The sympathetic branch of the autonomic nervous system is (partly) responsible for the “fight-or-flight” response. It thus increases the body’s readiness for action; heightening arousal and stress responses. The parasympathetic branch does the opposite. It prepares the system for “rest-and-digest”, dampening arousal and stress. Thus, phasically, high HRV means low stress, low HRV means high stress. Chronic stress is characterized by a tonic decrease in resting state HRV, through prolonged activity of the sympathetic nervous system (Choi et al., 2017). In overview, HRV is a good indicator of the flexibility and functional adaptability of the organic system to energy demands. Next, it also seems to be an indicator of cognitive flexibility.

Thayer and colleagues (2000, 2007) were the first to make a clear link between HRV and cognition. In their neurovisceral integration model they showed that high HRV is associated with increased cognitive control and flexibility. The model couples the function of the autonomic nervous system with that of central nervous system, through projections of the vagal nerve into prefrontal cortex. The neurovisceral integration model was recently adapted to new data and expanded on (Smith et al., 2017). This link between HRV and central nervous system functioning has since then been corroborated through many studies and across many domains; in some of these studies it is also reestablished that breathing at the optimal rate increases HRV, which then has an effect higher up the neural chain (Schwerdtfeger et al., 2020). For a recent review of HRV in psychological science see Pham et al. (2021). Concluding, HRV is a suitable indicator of the flexibility of both body and mind.

Arousal, stress, and relaxation

In many scientific texts the terms arousal and stress are used interchangeably and seem to stand for the same psychological construct. Regarding this demarcation, the current manuscript is not much different. Likewise, relaxation is usually defined as the absence of stress or arousal. In reality, there are many parts to the stress system, both in terms of temporal dynamics and mechanics. It is not even a single system. The autonomic nervous systems' sympathetic branch (Langley, 1903) is a separate system from the hypothalamic-pituitary-adrenal (HPA) axis (Sheng et al., 2021; Smith & Vale, 2022). Effects on these systems might also diverge. For example, traumatized individuals show heightened sympathetic nervous system responses to acute stress, while the HPA axis response is dampened, as compared to healthy controls (Schuurmans et al., 2021). Going even further, the effects on these separate stress systems can be divergent: patients suffering from post-traumatic stress disorder show tonically low salvatory cortisol levels (a HPA axis hormone) in the majority of studies, while sympathetic stress levels are high. So it seems that physiologically speaking at the same time these stress levels can be both low and high (Wahbeh & Oken, 2013a-b). Though note here that HPA activity is assumed to still be high, through higher sensitivity of corticosteroid-receptors. Another example of different roles of these stress systems: in panic disorder the sympathetic nervous system was long held responsible in the etiology of this psychopathology. Instead adrenaline/epinephrine seems to be the culprit of consensus currently; the autonomic nervous system no longer plays an explanatory role (Wilkinson et al., 1998).

The timing and duration of stress responses is of major consequence both in the processes triggered and in the effects sorted. For example, stress can both mobilize and immobilize the immune system depending on time scale (Sapolsky et al., 2000). The construct arousal also has very different mechanisms, that can work in concert or isolation, and do so in different timeframes. Even when the same chemical substance is involved, arousal can be reduced to different processes, depending on the site of action. Norepinephrine can act as a hormone or as a neurotransmitter. Both produce a form of arousal, but they diverge in timing and simultaneousness. In the relatively slow fight-or-flight response – effected by the hormone – the neurotransmitter is also acting on central nervous system sites. During the fight-or-flight response pupils dilate, a biomarker of central norepinephrine activity (Aston-Jones & Cohen, 2005; Gabay et al., 2011). But the involvement of the neurotransmitter here must be clearly disentangled from its neuromodulatory role in phasic arousal (Landman & Steenbergen, 2020), which acts on alertness moment-by-moment, or its function in the reticular activating system in waking up (Aston-Jones & Cohen, 2005; Berridge & Waterhouse, 2003, Kandel et al., 2000). These phenomena are not in concert with the endocrinal responses. Even within the fight-or-flight response, hormonal activity is associated more with the adrenocortical than the sympathetic norepinephrine response (Goldstein, 2010).

Relaxation is usually operationalized as the absence of stress or as a state of low arousal. Indeed, it is fair to say that if the HPA axis is not active or sympathetic activity is low, people are not stressed. However, concluding that this means that they are also relaxed is an inferential leap. For one, though the sympathetic and parasympathetic branch of the autonomic nervous system are mutually inhibitory and opposing in action, they can be active simultaneously. For example: when individuals recover from a stressor, both branches increase in activity (Weissman & Mendes, 2021). This realization leaves parasympathetic activity as the prime manner of assessing (active) relaxation and the development of valid measures of parasympathetic tone of heightened import.

As much as there are many possible definitions, interpretations and mechanizations of arousal, stress and relaxation, there are as many operationalizations. The measures intended to map these constructs are among others: pupillometry to measure central norepinephrine levels, blood sampling to measure stress hormones like cortisol, ECG for measuring vagal tone heart rate variability, ICG to measure sympathetic pre-ejection period, EEG to measure the frequency bands of overall brain activity, electrodermal activity to measure manual sweat secretion, and questionnaires to measure self-reported stress levels. After this expose, it is apparent and safe to say that most of these methodologies tap into different aspects and processes of the terms arousal, stress and relaxation. What is relevant here are the golden standards: the metrics where a scientific consensus exists that they map a certain aspect of autonomic activity.

Currently, the dominant measure of sympathetic (cardiac) activity is the pre-ejection period, obtained by using a combined ECG/ICG set-up. The dominant parasympathetic activity measure is (vagal tone) HRV by ECG. But there are significant differences between HRV metrics and not all metrics are equally suitable as indicators of cardiac vagal tone (Laborde et al., 2017). Two of the most widely used and accepted vagal tone HRV metrics are high frequency band HRV and the root mean square of successive differences

(RMSSD). In the not too distant past, the ratio measure between low frequency and high frequency HRV was also widely used to indicate the relative dominance between sympathetic activity (low frequency) and parasympathetic activity (high frequency). As such, it could have been a very useful indicator of the relative dominance of relaxation over stress in this work. However, the finding that low frequency HRV does not reliably reflect sympathetic tone (Martelli et al., 2014c) and that vagal or parasympathetic activity is also present in low frequency HRV (Billman, 2013), has precluded it for this aim. Instead within the empirical chapter where HRV data is collected we have consistently chosen RMSSD as the cardiac vagal tone measure. The reason for this choice, has to do with the influence of breathing. RMSSD is least influenced by respiratory patterns (Hill et al., 2009; Penttilä et al., 2001), while high frequency HRV is unreliable when respiration rates drop below 9 breaths/minute. This choice might seem paradoxical, as we are looking for effects of breathing on the autonomic nervous system. But as we are trying to ascertain whether any cognitive effects of breathing exercises are mediated by the cardiac branch of the vagus nerve, we instead hope to eliminate a potential confound. We seek to use the most valid measure of cardiac vagal tone within the context of our experiments.

This book is not the exception to the culture of muddling and conflating terms of arousal, stress and relaxation. Frequently, they are lacking clear neurophysiological or mechanistic definition in this book. However, when encountering these terms in the following text, the reader can safely assume that the authors are referring to autonomic activity, unless otherwise stated. Thus, when referring to arousal or stress this means high activity of the sympathetic nervous system, while relaxation refers to high activity of the parasympathetic nervous system, notably (cardiac) vagal tone. In my view, this will likely resolve most confusion, though probably not in all cases.

Bayesian statistics

In the empirical chapters of this dissertation all collected data is analyzed by Bayesian statistical counterparts of classical statistical tests. The reasons are clear: Bayesian statistics are robust and do not suffer from issues related to false positives or false negatives, if the study sample is large enough. There is also no multiple comparison issue; and most importantly: confident statements about the strength of evidence, for or against, can actually be made from these statistics (Wagenmakers et al., 2018). In short: it does not suffer from many of the ailments of classical p-testing and should be the statistics of choice in any probabilistic science. Certainly those sciences, such as psychology, that suffer a replication crisis and/or publication bias, where many canonical results can’t currently be replicated or many null-results — or even adverse results — are not being published; should take advantage of the Bayesian approach to statistical evidence.

For the convenience of the reader, I provide the following brief primer. Any Bayesian analysis – in our chapters these are mostly Bayesian repeated measures ANOVAs – produces a Bayesian odd for each model under comparison: the Bayesian factor (BF10). The factor gives the likelihood of the model under investigation being true, relative to the null-model. Note though, that it can also be compared to the best-fitting model in the complete analysis. In other words: this factor gives a quantification of the strength of evidence for any specific model, this in contrast to the all-or-nothing p-value. In the empirical chapters (**Chapter 3** and **Chapter 4**) we follow Jeffreys’ (1961, as adapted by Wetzels et al., 2011) qualification of Bayesian factor values. See table 1 for these qualifications of evidence load.

Table 1. Bayesian factors interpretation overview. BF_{10} is the likelihood that H_1 is true over H_0. H_1 is model 1; H_0 is null-model. Table taken and adapted from Wetzels et al. (2011).

Bayes factor (BF_{10})	Interpretation
> 100	Extreme evidence for H_1
30 - 100	Very strong evidence for H_1
10 - 30	Strong evidence for H_1
3 - 10	Moderate evidence for H_1
1 - 3	Anecdotal evidence for H_1
1	No evidence
1/3 - 1	Anecdotal evidence for H_0
1/10 - 1/3	Moderate evidence for H_0
1/30 - 1/10	Strong evidence for H_0
1/100 - 1/30	Very strong evidence for H_0
< 1/100	Extreme evidence for H_0

Overview

Though the order of this work follows date of publication (or writing) it is not strictly speaking chronological. The experiment reported in **Chapter 3** was published two years after the theoretical work in **Chapter 2**. However, the experiment of **Chapter 3** was set up and conducted some years before the main ideas of **Chapter 2** were formulated. Thus, these ideas were not set out to be tested in this experiment by design. The first experiment reported in **Chapter 4** was run during the time the manuscript of **Chapter 2** was being written. So the following chapters are anything but a smoothly flowing narrative.

Chapter 2 introduces a neurophysiological model that connects respiratory patterns with cognitive control, through mediation of the autonomic nervous system (Gerritsen & Band, 2018). The respiratory vagal nerve stimulation model (rVNS). One of the aims of the paper was to provide a framework from which to interpret and explain the many diverse findings of scientific publications on contemplative practices. For this aim, it also includes a selected review of that literature.

Chapter 3 presents a randomized controlled trial in a normally aging population (Gerritsen et al., 2021). The intervention consisted of a two-month online Tai Chi Chuan course and the experimental group was contrasted with an active control group that watched documentaries on similar topics of equal duration and frequency as the course. Participants were pre-post-tested on three executive functions: switching, updating and inhibition (Miyake et al., 2000); and (psycho)motorically scored on functional balance and motor speed.

Chapter 4 consists of two experiments that test some predictions of the rVNS model, that are expanded on in **Chapter 2**. Foremost, it was tested whether the locus of breathing – abdominal versus thoracic – has an effect on stress or relaxation (vagal tone) and on inhibitory control. In the first experiment the inhibition process under study is response inhibition, while in the second experiment it is cognitive inhibition (interference scores). Furthermore, the second experiment also tries to indirectly manipulate respiration rate and thus introduces another prediction of the rVNS model. As interventions, audio guided breathing exercises were used.

Finally, **Chapter 5** provides a summary of the previous three chapters. This is followed by a discussion which aims to give an in-depth analysis of the results and its implications. Lastly, the current state of contemplative science, but also of cognitive science in general, is critically discussed. **Chapter 5** has a Dutch copy right after the English version.