Meditation, Emotions and Visual Word Processing

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by

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– Viktor Emil Frankl

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Abbreviations

ALE	Activation Likelihood Estimation
EEG	Electroencephalography
e.g.	Latin: exempli gratia, English: for example
et al.	and others
fMRI	Functional Magnetic Resonance Imaging
Hz	Hertz
IFG	Inferior Frontal Gyrus
LDT	Lexical Decision Task
LIFG	Left Inferior Frontal Gyrus
MBSR	Mindfulness-Based Stress Reduction
MRI	Magnetic Resonance Imaging

Abbreviations in the empirical articles may diverge and are introduced in the respective articles.

Abstract

In the last decades, meditation has become the object of research in studies of various scientific disciplines. Meditation practice has been reported to regulate emotions, reduce mind wandering, and improve focused attention and working memory capacity. These are capabilities that are also related to visual processing of single words and to adequate and efficient reading comprehension. The impact of meditation on visual word processing and reading performance, however, is still insufficiently studied regarding several topics.

The present doctoral thesis reports whether and to what extent different meditation techniques (Zen, mindfulness, and loving-kindness) can influence visual word processing in lexical decision- and valence evaluation tasks. Further, it reports on the impact of mindfulness meditation on reading comprehension and reading speed.

Study 1 ($n = 40$) aimed at examining the impact of meditation on visual word processing in adept Zen meditators. The Zen group showed more neutral valence ratings of affective word stimuli and globally accelerated responses in the lexical decision task after a 90-minute meditation session. The comparison group did not show significant alterations in the experimental tests after the comparison intervention. In both groups, participants responded significantly slower to low-arousal negative words than to neutral words, which replicates a finding by Hofmann et al. (2009).

Study 2 ($n = 39$) compared the impact of mindfulness and loving-kindness meditation on visual word processing in meditation novices. Both meditation styles were found to lead to more neutral valence ratings of affective word stimuli and to globally accelerated responses in the lexical decision task. The loving-kindness meditation presented two distinctive features, it resulted in more positive valence ratings of positive words and led to the greatest acceleration of responses in the lexical decision task. The active control group did not show significant alterations in any of the assessments after the control intervention. In all three groups, participants responded significantly slower to low-arousal negative words than to neutral words, which is a replication of findings by Hofmann et al. (2009) and by study one.

Study 3 ($n = 52$) examined the influence of mindfulness meditation on reading comprehension and speed. Mindfulness meditation was found to improve reading comprehension but did not lead to a faster reading speed. In addition, this meditation style led to improved attentional capacity as well as improved emotion regulation in different dimensions. Neither improved attentional capacity nor enhanced emotion regulation

mediated the effect of improved reading comprehension through meditation practice. The active control group did not show significant changes after the control intervention regarding all experimental assessments.

In summary, the present doctoral thesis shows that different meditation techniques can influence visual word processing and reading comprehension. The first two studies presented evidence that meditation (Zen, mindfulness, and loving-kindness) led to globally faster responses in lexical decision tasks and to more neutral valence ratings of affective word stimuli. Loving-kindness meditation led to more positive valence ratings of positive words. The third study provided evidence that mindfulness meditation led to enhanced reading comprehension, focused attention, and emotion regulation but did not have an impact on reading speed.

These findings extend current research in addressing inconclusive results on the impact of meditation on reading comprehension. Further, they indicate that meditative exercises could be an effective method to support the regular treatment of difficulties in reading comprehension. The results give also relevant indications for studies, which use psycholinguistic experiments. Participants' experience of meditation practice should be considered an individual difference that has the potential to significantly alter study results, especially when using lexical decision tasks, valence rating tasks, or word stimuli that were selected on the basis of valence ratings.

Zusammenfassung

In den letzten Jahrzehnten ist Meditation in Studien verschiedener wissenschaftlicher Disziplinen zum Forschungsgegenstand geworden. Es wurde berichtet, dass die Meditationspraxis Emotionen reguliert, das Umherschweifen der Gedanken verringert und die konzentrierte Aufmerksamkeit sowie die Kapazität des Arbeitsgedächtnisses verbessert. Dies sind Fähigkeiten, die auch mit der visuellen Verarbeitung einzelner Wörter und einem angemessenen und effizienten Leseverständnis zusammenhängen. Die Auswirkungen der Meditation auf die visuelle Wortverarbeitung und die Leseleistung sind jedoch in Bezug auf mehrere Themen noch unzureichend untersucht.

In der vorliegenden Dissertation wird untersucht, ob und in welchem Ausmaß verschiedene Meditationstechniken (Zen, Achtsamkeit und Liebende-Güte) die visuelle Wortverarbeitung in lexikalischen Entscheidungs- und Valenzbewertungsaufgaben beeinflussen können. Des Weiteren wird über die Auswirkungen von Achtsamkeitsmeditation auf das Leseverständnis und die Lesegeschwindigkeit berichtet.

In Studie 1 (n = 40) wurden die Auswirkungen von Meditation auf die visuelle Wortverarbeitung bei erfahrenen Zen-Meditierenden untersucht. Die Zen-Gruppe zeigte nach einer 90-minütigen Meditationssitzung neutralere Valenzbewertungen bei affektiven Wortstimuli und global beschleunigte Reaktionen in der lexikalischen Entscheidungsaufgabe. Die Vergleichsgruppe zeigte nach der Vergleichsintervention keine signifikanten Veränderungen in den experimentellen Tests. In beiden Gruppen reagierten die Teilnehmenden signifikant langsamer auf Wörter mit geringer negativer Erregung als auf neutrale Wörter, was einen Befund von Hofmann et al. (2009) repliziert.

In Studie 2 (n = 39) wurden die Auswirkungen von Achtsamkeits- und Liebende-Güte-Meditation auf die visuelle Wortverarbeitung von Meditationsanfängern verglichen. Beide Meditationsstile führten zu neutraleren Valenzbewertungen bei affektiven Wortreizen und zu global beschleunigten Reaktionen bei der lexikalischen Entscheidungsaufgabe. Die Liebende-Güte-Meditation wies zwei Besonderheiten auf, sie führte zu positiveren Valenzbewertungen bei positiven Wörtern und zu einer stärkeren Beschleunigung der Reaktionen in der lexikalischen Entscheidungsaufgabe. Die aktive Kontrollgruppe zeigte nach der Kontrollintervention keine signifikanten Veränderungen bei den experimentellen Untersuchungen. In allen drei Gruppen reagierten die Teilnehmenden signifikant langsamer auf Wörter mit geringer negativer Erregung als auf neutrale Wörter, was eine Replikation der Ergebnisse von Hofmann et al. (2009) und von Studie 1 darstellt.

Studie 3 (n = 52) untersuchte den Einfluss der Achtsamkeitsmeditation auf das Leseverständnis und die Lesegeschwindigkeit. Es zeigte sich, dass Achtsamkeitsmeditation das Leseverständnis verbessert, aber nicht zu einer höheren Lesegeschwindigkeit führt. Darüber hinaus führte dieser Meditationsstil zu einer verbesserten Aufmerksamkeitskapazität sowie zu einer verstärkten Emotionsregulation in verschiedenen Dimensionen. Weder die verbesserte Aufmerksamkeitskapazität noch die verbesserte Emotionsregulation vermittelten den Effekt des verbesserten Leseverständnisses durch die Meditationspraxis. Die aktive Kontrollgruppe zeigte nach der Kontrollintervention keine signifikanten Veränderungen in allen experimentellen Untersuchungen.

Zusammenfassend zeigt die vorliegende Dissertation, dass verschiedene Meditationstechniken die visuelle Wortverarbeitung und das Leseverständnis beeinflussen können. Die ersten beiden Studien zeigten, dass Meditation (Zen, Achtsamkeit und Liebende-Güte) zu global schnelleren Reaktionen in lexikalischen Entscheidungsaufgaben und zu neutraleren Valenzbewertungen bei affektiven Wortreizen führte. Die Meditation der Liebenden-Güte führte zu positiveren Valenzbewertungen bei positiven Wörtern. Die dritte Studie lieferte Belege dafür, dass Achtsamkeitsmeditation zu einem verbesserten Leseverständnis, zu verbesserter fokussierter Aufmerksamkeit und verstärkter Emotionsregulation führt, aber keinen Einfluss auf die Lesegeschwindigkeit hat.

Diese Ergebnisse erweitern den aktuellen Forschungsstand indem sie widersprüchliche Befunde zu den Auswirkungen von Meditation auf das Leseverständnis beleuchten. Darüber hinaus deuten sie darauf hin, dass meditative Übungen eine wirksame Methode sein könnten, um die reguläre Behandlung von Schwierigkeiten beim Leseverständnis zu unterstützen. Die Ergebnisse geben auch wichtige Hinweise für Studien, die psycholinguistische Experimente verwenden. Die Erfahrung der Teilnehmenden mit der Meditationspraxis sollte als individueller Unterschied betrachtet werden, der das Potenzial hat, Studienergebnisse signifikant zu verändern, insbesondere wenn lexikalische Entscheidungsaufgaben, Valenzbewertungsaufgaben oder Wortstimuli verwendet werden, die auf der Grundlage von Valenzbewertungen ausgewählt wurden.

1 Introduction

"He who knows how to read holds the key to great deeds, to undreamed-of possibilities." – Aldous Huxley

The ability of good reading comprehension is essential to succeed in today's society in many aspects. It is one of the most important skills for a successful school and working career and also important to manage in everyday life. However, adequate reading comprehension is a skill that a considerable number of schoolchildren still lack. The 2018 Program for International Student Assessment (PISA) study showed that about 20 percent of students at age 15, who were tested in Germany, were unable to capture and reflect on the meaning of written texts (PISA, 2019). A recent study reported that 25 percent of the tested German fourth graders do not reach the basic level of reading comprehension (McElvany et al., 2023).

Among other things, sustained attention, good working memory capacity, reduced mind wandering, and emotion regulation affect reading comprehension and single word processing (Arrington et al. 2014; Carretti et al., 2009; Daneman and Merikle, 1996; Sereno et al., 2015; Smallwood, 2011; Reichle et al., 2010). Meditation practice was reported to have an impact on all of these capabilities (Blanck et al., 2018; Chambers et al., 2008; Mrazek et al., 2012; Quach et al., 2016). However, direct effects of meditation on word processing and reading performance are still insufficiently studied and present inconclusive results. Clinton et al. (2018) and Mrazek et al. (2013) reported that meditation practice influenced reading comprehension positively. Linden (1973), on the other hand, found that an 18-week meditation intervention did not affect participants' reading comprehension. A study by Benney et al. (2021) could not give conclusive results on the question of whether mindfulness meditation can enhance reading fluency.

This doctoral thesis examines this rarely studied area of research to answer the question of whether meditation techniques can help people better understand the meaning of written texts. Further, it examines a possible influence of meditation on reading speed and on the processing time of single words.

Another focus of the present doctoral thesis is the question of whether meditation practice can regulate the valence ratings of affective words. Meditation practice was found to regulate negative emotions, as it can promote the reduction of depression (Grecucci et al., 2015; Tang et al., 2007), anxiety (Hofmann et al., 2010; Tang et al., 2007), and also stress (Goyal et al., 2014). While meditation was also found to reduce the emotional impact of affective images (Chau et al. 2018; Desbordes et al., 2012; Ortner et al., 2007), there is a lack of evidence for the impact of meditation on affective word processing. This research gap is addressed in the present doctoral thesis.

2 Theoretical background

2.1 Origins and definitions of the term "meditation"

From which language the word "meditation" originates is not conclusively clarified, but it seems likely that it has an origin in the Latin language. "Medi" in Latin means "middle", "tation" is a reference to an active process. Therefore, "coming to the middle", might be a good translation for the word "meditation". Another possibility is that "meditation" originates from the Latin term "meditation", which means "reflection" (Piron, 2020).

Regarding the academic literature on meditation, no agreement can be found on the definition of meditation. This problem is based on the great variety of meditation methods (Bond et al., 2009; Nash et al., 2013). Trying to find a solution to the problem, Bond et al. (2009) interviewed seven adept meditation researchers on the classification of meditation. Using the Delphi method, authors reported that the expert researchers agreed on the following criteria as being essential to meditation:

"(a) a defined technique,
(b) logic relaxation, and
(c) a self-induced state/mode" (Bond et al., 2009, p. 132).

The meditation researchers accorded also that meditation *can*:

"(d) involve a state of psychophysical relaxation somewhere in the process;
(e) use a self-focus skill or anchor;
(f) involve an altered state/mode of consciousness, mystic experience, enlightenment, or suspension of logical thought processes;
(g) be embedded in a religious/spiritual/philosophical context; or
(h) involve an experience of mental silence" (Bond et al., 2009, p. 132).

In addition to this classification of criteria that fit meditation practice, meditation can also be defined by the categorization of mental training methods, considering especially the direction of the attentional processes. Lutz et al. (2008) introduced the classification of meditation into two main categories, which are focused attention meditations and open monitoring meditations.

Many Buddhist meditation techniques use focused attention meditation. The practitioner chooses an object, for example, the breath, and tries to keep his focus in every moment on this object. When the meditator notices that his attention is wandering, he should acknowledge that without judgment and gently redirect his attention to the chosen object. The practitioner can measure his progress by looking at the effort he has to make to keep his attention on the object. Beginning meditators experience more distractions than adept practitioners. The more experienced a meditator is, the faster he can return to his chosen object of concentration. Experienced meditators have no difficulty at all in keeping their attention on the chosen object (Lutz et al., 2008).

Often in the beginning of open monitoring meditation practitioners use focused attention to focus and calm their minds. During the main open monitoring meditation, the meditator tries to monitor the experience of each moment, he does not focus on any object and tries not to get further involved with what he feels, hears, and thinks. The practitioner lets these experiences come and go, without any judgment. One of the main goals of this meditation is to develop a non-emotionally reactive but reflexive awareness of one's mental state (Lutz et al., 2008).

2.2 A short history of meditation

It is not possible to trace back exactly when humans began to meditate. However, some archeologists assume that our homo sapiens ancestors must have already known meditative states. They may have practiced so-called “campfire rituals of focused attention”, which could have helped them to improve their working memory capacities (Rossano, 2007).

2.2.1 Yoga

Yoga is the oldest well-documented meditation practice and has its origin in India. It is estimated that the tradition of yoga originated between 2500 to 5000 years ago. The earliest depiction of a yogi known to us was found in the Indus Valley. A seal made of soapstone shows a yogi sitting with crossed legs; it dates back to the 3rd millennium BC (Pandurangi et al., 2017). Yoga is often taught within Hinduism, but generally, it is detached from religious traditions. Different styles of yoga have gradually developed, but all of them focus on the training of concentration in interaction with breathing. Yoga with a focus on controlled physical postures (the Asanas), as taught nowadays in fitness centers, is a comparatively new style (Piron, 2020). The writings (sutras) of Patanjali (between 600 BC and 200 AD) probably had the greatest influence on the formation of modern yoga. The yoga path described there is divided into eight stages:

1. The outer discipline: non-violence, truthfulness, non-stealing, abstinence, and non-possessiveness (Yama)
2. The inner discipline: purity, contentment, asceticism, self-reflection, and devotion (Niyama)
3. The postures (Asanas)
4. The regulation of the breath (Pranayama)
5. Restraining the senses from the environment (Pratyahara)
6. Concentration (Dharana)
7. Meditation (Dhyana)
8. The immersion (Samadhi) (Bretz, 2001; Pandurangi et al., 2017; Piron, 2020).

2.2.2 Theravada Buddhism

Theravada Buddhism is the oldest Buddhist school still practiced today. It is based on the teachings of the Buddha, which were first transmitted orally by his disciples. The Buddha was born under the name Siddharta Gautama around 500 BC. After becoming enlightened under the Bodhi tree, he taught a way of life that should be free from extremes. In 500 AD, the teachings of Buddha were summarized in writing by Buddhaghosa, these writings are the basis of Theravada Buddhism. Two basic types of meditation are taught there. First, concentrative meditation (samatha) should be practiced to calm the mind; in the second step, practitioners should practice insight meditation (vipassana) to attain wisdom. During samatha, the meditator focuses on a particular object, attention is gently returned to the object each time the mind digresses. This way a constant focused awareness can be achieved. During Vipassana the practitioner does not focus on any object. Instead, all thoughts, feelings, and emotions that arise are consciously perceived and then let go without evaluating them further (Piron, 2020).

2.2.3 Tibetan Buddhism

About 500 years after the death of the Buddha, the Mahayana Buddhism developed. This form of Buddhism had set itself the task of making the Buddha's teachings comprehensible to all people, not only to Buddhist monks. From Mahayana Buddhism eventually developed Tibetan Buddhism, whose most famous representative today is the Dalai Lama. The "nine stages of meditative stabilization" is one of the most important texts in Tibetan Buddhism and was written around 500 AD. It describes that the goal of concentrative meditation is a calm and peaceful mind to achieve a continuous, balanced stabilization of thoughts and feelings (Piron, 2020).

2.2.4 Zen Buddhism

Around 500 AD, Mahayana Buddhism was introduced to China and developed into its own school, the Chan Buddhism, between 618 and 917 AD. The word ‘Chan’ means ‘meditation’ and its Japanese translation is ‘Zen’. This term not only includes concentrated seated meditation (zazen), but also the cultivation of an alert, attentive, and clear mind (Piron, 2020). In Japan, Zen Buddhism evolved around the 12th century (Dumoulin, 1990). The Zen monasteries were located in the mountains, far from the cities. There, the monks could not live from alms and practiced agriculture themselves. The Zen monks, therefore, practiced not only during sitting meditation to focus and calm their minds but also combined the meditative practices with all their everyday duties (Piron, 2020).

2.2.5 Christian Meditation

Meditation practices can also be found in the Christian tradition, for example, among the so-called "Desert Fathers", who were early Christian monks. Starting from the 3rd century, they lived in the solitude of the desert. One of them was Johannes Cassianus, he practiced the constant repetition of a single word to calm the mind and applied a prayer without images and words. Both these practices can be seen as a form of meditation (Jäger, 1999; Piron, 2020). Such contemplative prayers were also practiced by Meister Eckhart (1260–1328 AD) and Teresa of Ávila (1515– 1582 AD) (Piron, 2020).

2.2.6 Meditation in the West

In the 1970s and 80s, meditation became increasingly popular in Western countries. Especially in the United States of America, meditation was now also scientifically studied.

Pioneers in the field were Herbert Benson and Jon Kabat-Zinn. Both subsequently developed their own meditation interventions, which were primarily intended to help people with psychological and physical health problems (Benson et al., 1974; Kabat-Zinn, 2013). Kabat-Zinn's Mindfulness-based stress reduction (MBSR) program is applied worldwide today and has been the subject of numerous scientific studies (Kabat-Zinn, 2003).

2.3 Meditation techniques used in the three studies of the doctoral thesis

Zen Meditation

Zen is a Buddhist practice and came to Japan between the 11th and 12th centuries, "Zen" can be called the "school of meditation". "Zazen" means in Japanese "seated meditation". The most famous Zen branches are Rinzai and Soto. In its pursuit of enlightenment, a key element of Soto Zen is deep meditation (zazen), and can be considered a more intellectual method. The practitioner is instructed to sit and try to reach a mental state without thinking. Rinzai Zen uses a more direct approach and a key element is the use of koans (paradoxical riddles) (Bielefeldt, 1990; Dogen, 1972; Nash et al., 2013).

Mindfulness meditation

Mindfulness meditation originates from (Zen) Buddhist meditation traditions (Hanh, 1976). Bishop et al. (2004) argued that mindfulness consists of two elements. At first, the practitioner has to learn to regulate his attention, in this way, he can focus on the present moment without being distracted by thoughts, emotions, feelings, and noises. In the second step, all present-moment experiences, even the unpleasant ones, should be faced with interest, acceptance, and openness. According to Kabat-Zinn (2013), the main element of mindfulness is that the practitioner looks at all experiences of the present moment with non-judgmental attention. Mindfulness is often practiced with sitting- but also with walking-meditations.

Loving-Kindness Meditation

Buddhist traditions specifically highlight the significance of cultivating relatedness and love for others, which can be practiced through techniques such as loving-kindness meditation. During loving-kindness meditation, the practitioner tries to develop warm, kind feelings and compassion first for himself. Then these kind and warm feelings of compassion are gradually extended to others, to family members, loved ones, to people for whom the practitioner had unpleasant feelings, and finally to all living beings (Hutcherson et al., 2008; Kang et al., 2014).

2.4 Research on the effects of meditation practice

Over the past few decades, numerous scientific studies have been conducted to examine the effects of meditation. Especially mindfulness meditation is widely studied. It is desirable that we gain a growing knowledge of the practice of meditation. However, it must be noted that many findings from meditation studies still have to be replicated and that several meditation studies lack methodological quality since they have small sample sizes and are not actively controlled studies with a longitudinal design (Tang et al., 2015). In addition, there is a severe bias for publishing positive or significant results in meditation studies, as a meta-analysis showed (Fox et al., 2014). The following section presents key studies on the effects of different meditation styles, divided into behavioral, electroencephalographic, and functional magnetic resonance imaging studies. Study results are also summarized in Table 1.

2.4.1 Behavioral Studies

Clinical disorders: Mindfulness meditation was reported to be a useful tool to support the reduction of some clinical disorders. A long-term practice in mindfulness meditation, for instance, helped to reduce substance misuse, craving, stress (Li et al., 2017), and binge-eating (Godfrey et al., 2015).

Health: In a systematic review, Black and Slavich (2016) suggested that mindfulness meditation practice tends to have a positive influence on the immune system. However, the studies on this topic are very heterogeneous and their explanatory power is partly limited. Rainforth et al. (2007) conducted a meta-analysis to examine different stress reduction techniques (including meditation) and their effectiveness in lowering blood pressure. Their calculations suggested that transcendental (mantra) meditation is an effective tool to reduce blood pressure. Several meditative practices appear to be effective in reducing cortisol-levels in individuals at risk for elevated cortisol levels but not in no-risk individuals (Koncz et al., 2021). A meta-analysis by Hilton et al. (2017) showed that mindfulness meditation can only produce a minor decrease in pain symptoms and that the evidence for it is of low quality. The MBSR program was found to effectively reduce psychological stress in healthy participants but did not appear to be more effective than standard relaxation training (Chiesa & Serretti, 2009). Further, mindfulness interventions were reported to be a helpful tool against COVID-19 related psychological stress (Duarte et al., 2022).

Emotion regulation: Meta-analyses suggest that different meditative practices have good efficacy in treating anxiety symptoms (Blanck et al., 2018; Chen et al., 2012; Hofmann et al., 2010) and symptoms of depression (Blanck et al., 2018; Hofmann et al., 2010). In addition, meditation practitioners seem to have a greater ability to regulate their emotions when confronted with affective images (Arch & Craske, 2006). Further, a survey study by Lo and Wu (2007) showed, that Zen meditation is associated with a lower occurrence of depression, anxiety, and perceived stress in college students.

Attention: Sumantry and Stewart (2021) found in their recent meta-analysis that focused attention and open monitoring meditations are associated with an increase in generalized attention. Specifically, attention, orienting, and executive control networks were improved. Dimensions of executive control such as inhibition and shifting also enhanced after meditation practice.

Working memory: The randomized control trial of Bonamo et al. (2015) showed that mindfulness meditation can enhance working memory capacity regarding the encoding of novel words. Quach et al. (2016) reported increased working memory capacity following a mindfulness intervention using the Automated Operational Span Task as a measurement tool.

Reduced mind wandering: A study by Mrazek et al. (2012) showed that a brief mindful breathing instruction led to reduced mind wandering. Rahl et al. (2017) reported that a brief mindfulness practice, which included an acceptance mindfulness training, led to the lowest mind wandering compared to a mindfulness training without acceptance condition and to other control conditions.

Self-awareness: A qualitative analysis of meditation diaries, that participants of an 8-week MBSR class had written, showed that the practitioners developed an “observing self” during the meditation practice (Kerr et al., 2011). Haimerl and Valentine (2001) reported that the more experienced Buddhist meditators were, the less they exhibited self-concept styles associated with pathological symptoms.

Self-regulation: It is proposed that mindfulness training enhances self-regulation, which is constituted by the interaction of altered self-awareness, improved attentional control, and emotion regulation (Tang et al., 2015; Hölzel et al., 2011; See Figure 1).

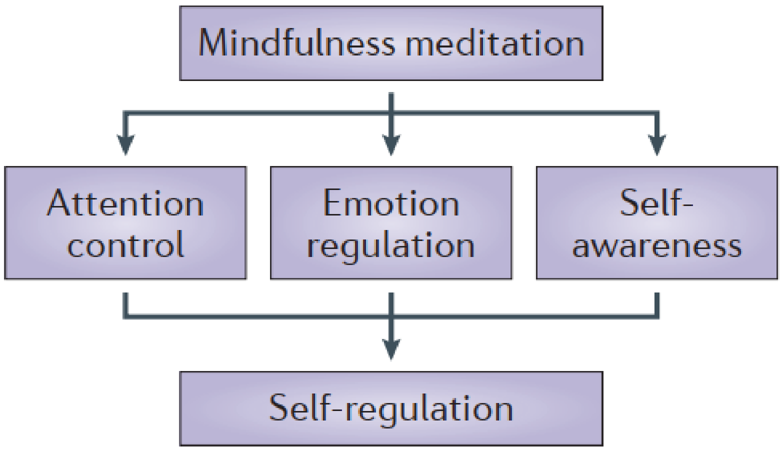

Figure 1. Mindfulness meditation and its relation to self-regulation, taken from Tang et al. (2015)

2.4.2 Electroencephalography (EEG) studies

An early review of the effects of meditation on EEG changes was written in 1980 by West. Reviewing several studies of different meditation styles, he reported that meditation sessions are initially often accompanied by a decreased alpha frequency and an increased alpha amplitude (Kasamatsu & Hirai, 1966; Wallace, 1970; West, 1980). Theta waves usually occur shortly before sleep. In many meditation studies, though, theta waves (6-7 Hz) occurred in fully awake meditators, mostly in very experienced ones (Kasamatsu & Hirai, 1966; Wallace, 1970, 1971; West, 1980). During stages of deep meditation, fast beta and gamma waves (20-40 Hz) were reported (Banquet, 1972, 1973). They can be associated with a strong focused attention (Sedlmeier, 2016; West, 1980).

In a systematic review by Lomas et al. (2015), the authors examined 56 studies, which addressed EEG and mindfulness meditation. They compared changes in the EEG during meditation with changes in the EEG when the participants were not meditating but had their eyes closed. Their results suggested that meditation is associated with enhanced theta and alpha power. For beta, delta, and gamma bandwidths, the authors found no consistent patterns that were caused by meditation. They interpreted the enhanced alpha and theta power as a state of relaxed attention (Lomas et al., 2015). Adept Sahaja Yoga meditators showed at rest increased alpha and theta power in comparison to age-matched control-participants (Aftanas & Golosheykin, 2005). A study with 40 participants by Khare and Nigam (2000) also suggested that enhanced alpha power is an effect of transcendental and Yoga meditation.

2.4.3 Functional magnetic resonance imaging (fMRI) studies

Using a meta-analysis with fMRI studies, Boccia et al. (2015) examined the effects of meditation (without restriction to a particular style) on brain function and structure. They compared the neuroimaging data of these studies with an activation likelihood estimation (ALE) analysis. The authors found that meditation practice activated several brain areas, which are associated with self-regulation, adaptive behavior, focused problem-solving (anterior cingulate cortex), the processing of self-relevant information (precuneus), and the perception of inner processes (insula). Tomasino et al. (2014) conducted also an fMRI meta-analysis using an ALE analysis. They compared the effects of Hindu and Buddhist meditation on the activation of brain regions. The results of their analysis indicated that Buddhist meditation activated mostly frontal lobe structures, which are engaged with executive attention. Hindu meditation, on the other hand, activated mostly the posterior parietal and temporal lobes.

Fox et al. conducted in 2016 an ALE-meta-analysis of 31 functional neuroimaging studies on the effects of long-term meditation practice on brain activation. They divided the meditation techniques into four styles: a) focused attention, b) mantra recitation, c) open monitoring, and d) compassion/loving-kindness. During focused attention meditation, activations were found in brain regions, which are associated with the voluntary control of actions and thoughts (premotor cortex, dorsal anterior cingulate cortex). Deactivations during focused attention meditation were detected in regions, which are associated with conceptual processing and episodic memory (ventral posterior cingulate cortex, left inferior parietal lobule). The inferior parietal lobe is also associated with processes of attention and language, and with social cognition (Numssen et al., 2021). Further, in the study by Fox et al. (2016), during mantra meditation deactivations in regions associated with the processing of viscero-somatic body signals (left anterior insula) were found. Activations were found in regions responsible for willingly executing and planning motor output (premotor cortex, supplementary motor area, putamen, lateral globus pallidus) and for visual processing and mental imagery (fusiform gyrus, cuneus, precuneus). For open monitoring meditation, the analysis resulted in activations in regions, that are associated with conscious action management (premotor cortex, inferior frontal gyrus, supplementary motor area, and pre-supplementary motor area). Further activations were reported for the insula, responsible for the conscious monitoring of viscero-somatic body signals. Deactivations were found in the thalamus. During compassion and loving-kindness meditation regions responsible for empathy and conscious body sensations and feelings (anterior insula, frontal operculum) were activated. In addition, the parieto-occipital sulcus and the inferior parietal lobule were activated while the practitioners meditated (Fox et al., 2016).

An ALE meta-analysis on the effects of mindfulness meditation on brain region activity was performed by Falcone and Jerram (2018). Analyzing 21 studies, they reported that the insula, the anterior cingulate, and frontal regions were activated during mindfulness meditation. Novices showed just activations in the insula and adept meditators in the globus pallidus and the medial frontal gyrus.

Table 1. Overview of key studies that examined main effects of meditation practice

Study name	Meditation Style	*n*	Study Type	Findings
Behavioral studies				
Arch & Craske, 2006	Focused breathing induction	60	Pretest-posttest	Emotion regulation in response to affective images
Black & Slavich, 2016	Mindfulness meditation	1602	Systematic review	Possible positive influence on immune system
Blanck et al., 2018	Mindfulness meditation	1150	Meta-analysis	Reduction of anxiety and depression symptoms
Bonamo et al., 2015	Brief mindfulness exercise	136	Randomized controlled trial	Enhancement of working memory capacity
Chen et al., 2012	Meditation-related therapies	2466	Meta-analysis	Reduction of anxiety symptoms
Chiesa & Serretti, 2009	MBSR	671	Meta-analysis	Reduction of stress, ruminative thinking, and trait anxiety, increase in empathy and self-compassion.
Duarte et al., 2022	Mindfulness-based interventions	12904	Systematic review	Reduction of COVID-19 related psychological stress
Godfrey et al., 2015	Mindfulness meditation	1095	Meta-analysis	Reduction of binge-eating

Haimerl & Valentine, 2001	Buddhist meditation	159	Cross-sectional study	Less self-concept styles with pathological symptoms
Hilton et al. 2017	Mindfulness meditation	3536	Meta-analysis	Small decrease in pain symptoms, reduction of depression symptoms, increased quality of life
Hofmann et al., 2010	Mindfulness-based therapy	1140	Meta-analytic review	Reduction of anxiety and depression symptoms
Koncz et al., 2021	No limitation to a specific meditation style	1810	Meta-analysis	Reduction of cortisol levels in high-risk (but not no-risk) individuals.
Li et al., 2017	Mindfulness meditation	5505	Meta-analysis	Reduction of substance misuse, craving, stress
Lo & Wu, 2007	Zen meditation	541	Survey study	Association of Zen meditation with lower depression, anxiety, and stress
Mrazek et al., 2012	Mindful breathing	60 (Study 2)	Randomized controlled trial (Study 2)	Reduction of mind wandering (Study 2)
Quach et al., 2016	Mindfulness meditation	198	Randomized controlled trial	Enhancement of working memory capacity
Rahl et al., 2017	Brief mindfulness meditation (with and without acceptance condition)	147	Randomized controlled trial	Lowest mind wandering in mindfulness + acceptance condition
Rainforth et al., 2007	Transcendental meditation	960	Meta-analysis	Reduction of blood pressure

Sumantry & Stewart, 2021	Focussed attention and open monitoring meditation	5003	Meta-analysis	Increase in different attention capacities
EEG Studies				
Aftanas & Golosheykin, 2005	Sahaja Yoga meditation	50	EEG study	increased alpha and theta power at rest
Khare & Nigam, 2000	Transcendental and Yoga meditation	40	EEG study	enhanced alpha power during and after meditation
Lomas et al., 2015	Mindfulness meditation	1715	Systematic review	enhanced alpha and theta power during meditation
West, 1980	No limitation to a specific meditation style	Not specified	Review	increased alpha amplitude, decreased alpha frequency, theta waves in fully awake meditators, fast beta and gamma waves during deep meditation stages
fMRI Studies				
Boccia et al., 2015	No limitation to a specific meditation style	2875	Meta-analysis	Activation of anterior cingulate cortex, precuneus, and insula
Falcone & Jerram, 2018	Mindfulness meditation	359	Meta-analysis	Activation of insula, the anterior cingulate, and frontal regions during meditation
Fox et al., 2016	Focused attention, mantra recitation, open monitoring, compassion/loving-kindness meditation	527	Meta-analysis	During focused attention meditation: activation of premotor cortex, dorsal anterior cingulate cortex. Deactivations of ventral posterior cingulate cortex, left inferior parietal lobule.

				During open monitoring meditation: activation of inferior frontal gyrus, pre-supplementary motor area, supplementary motor area, premotor cortex, insula. Deactivation of thalamus. During Mantra meditation: Activation of premotor cortex, supplementary motor area, putamen, lateral globus pallidus, fusiform gyrus, cuneus, precuneus. Deactivation of left anterior insula. During compassion and loving-kindness meditation activation of anterior insula, frontal operculum, parieto-occipital sulcus, inferior parietal lobule.
Tomasino et al., 2014	Hindu versus Buddhist meditation	329	Meta-analysis	Activation of frontal lobe structures in Buddhist meditators, Activation of posterior parietal and temporal lobes in Hindu meditators

2.5 Possible problems and risks of meditation practice

For novices, it tends to be difficult to firmly integrate the meditation practice into their existing daily routine. Often the meditation practice is abandoned after a few weeks because no lasting routine can be formed (Delmonte, 1988; Sedlmeier, 2016). In addition, various sitting positions in which meditation is performed can cause pain. Especially the crossed position of the legs can be painful at the beginning and lead to cramps. The biggest problem for meditation novices, but also for adept meditators, may be the confrontation with unpleasant feelings and thoughts. During meditation practice, one withdraws from any distraction and should allow feelings, sensations and thoughts to come and pass without judging them. Sooner or later, meditators are confronted in this way with feelings and thoughts that they would normally like to avoid. This tendency is reflected in the results of a study in which almost half of the participants preferred to receive a mild electric shock than to sit and do nothing for 15 minutes (Kornfield, 1979; Sedlmeier, 2016). In particular, people with psychiatric disorders should be guided in their meditation practice by a well-trained meditation teacher and should meditate in a group if possible. Otherwise, the practice of meditation could lead to an aggravation of their condition. General caution is advised with extreme meditation practices (Sedlmeier, 2016). A recent meta-analysis came to the conclusion that individuals with higher psychopathology scores demonstrated a deterioration of mental health after meditation practice (Buric et al., 2022).

2.6 Affective word processing

2.6.1 The influence of valence and arousal on word processing

For decades, the research on affective word processing has examined the influence of emotional valence on visual word processing. Several studies, that used the lexical decision task (LDT), the emotional Stroop task, or similar assessments, came to the result that negative words are processed slower than neutral and/or positive words (e.g., Algom et al., 2004; Kahan & Hely, 2008; Wentura et al., 2000). According to the hypothesis of automatic vigilance (Pratto & John, 1991; Wentura et al., 2000) these results support the idea that threatening information, such as negative words, attracts attention and holds it longer than neutral or positive information (Fox et al., 2001). In the current research literature, it is well known that various word properties can affect word processing such as number of syllables, imageability, number of letters, and word frequency (Hofmann et al., 2007; Kuchinke et al., 2007; New et al., 2006). However, a great number of linguistic studies did not control for such variables. Larsen et al. (2006) re-analyzed 32 published studies that used the emotion Stroop task, examining 1033 stimulus words. After the authors had controlled the stimulus words for word frequency and word length, negative words no longer resulted in slower response times than neutral words. These results challenge the hypothesis of automatic vigilance.

Many studies, that used well-controlled stimulus material, found that positive and negative words elicited equally fast response times and were processed faster than neutral words (e.g., Kousta et al., 2009; Scott et al., 2009; Vinson et al., 2014; Yap & Seow, 2014). However, there are also several studies, which showed that positive words are processed faster than neutral and negative words (e.g., Gao et al., 2022; Kuchinke et al., 2005, 2007). Contradictory results on response times to emotionally valenced words can be partially explained when the word property of arousal is taken into account (cf. Hofmann et al., 2009). Affect can be subdivided into two categories - valence and arousal. Affective valence describes the dimension of perceived unpleasantness or pleasantness, that is, if a stimulus is perceived as positive or negative. Positive valence is assumed to generate approach, and negative valence to generate withdrawal. Arousal describes the intensity, i.e., whether the affect is perceived as calming or arousing (Bradley & Lang, 1999; Lang et al., 1997; Osgood et al., 1957). Usually, a stimulus that is perceived as very positive or very negative is also perceived as more arousing (Bradley & Lang, 1999). Often in studies on emotion word processing, negatively valenced words receive higher arousal ratings than positively valenced words (Citron et al., 2014b; Montefinese et al., 2014; Vo et al., 2009) as can also be seen in Figure 2.

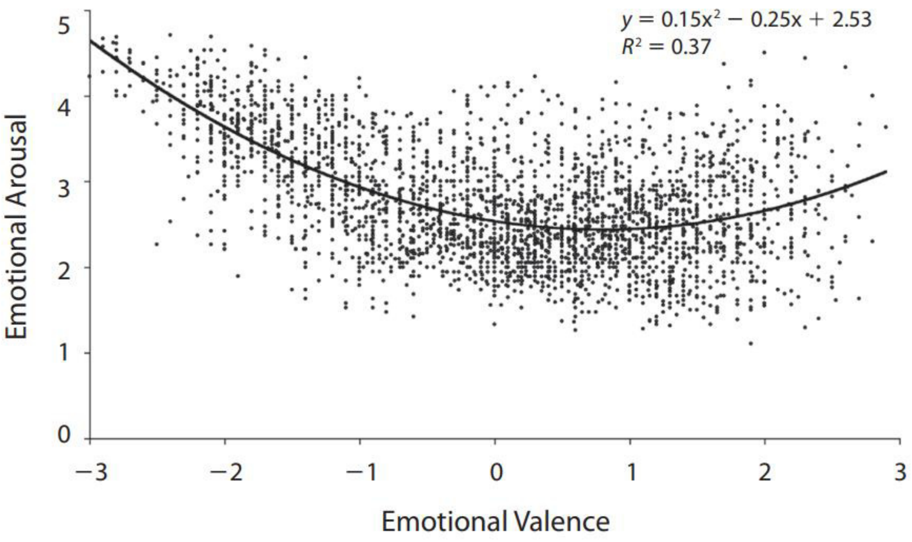

Figure 2. Berlin Affective Word List - Distribution of mean values for all words, taken from Vo et al. (2009)

Hofmann et al. (2009) controlled their stimulus material for arousal ratings and various other variables such as number of orthographic neighbors, mean letter frequency, imageability, word frequency, and emotional valence. Twenty participants performed an LDT with 50 positive, neutral, low-arousal negative, and low-arousal negative words each. They reported that high-arousal negative and positive word stimuli were processed faster than neutral words. Low-arousal negative words were processed slower than neutral words. These results show that arousal strongly affects emotion word processing. Another study, with well-controlled stimulus material, found similar results: Bayer et al. (2012) reported that low-arousal negative words were processed slower than high-arousal negative, positive, and neutral words. Kuperman et al. (2014) found a different pattern. In their study, the responses to arousing words were slower than the responses to non-arousing words.

The results of a study by Citron et al. (2014a) showed that participants responded slower to high-arousal positive and low-arousal negative words than to low-arousal positive and high-arousal negative words. The authors interpreted these results as being in line with a model of approach and avoidance by Robinson et al. (2004). The model by Robinson et al. (2004) proposed that high-arousal stimuli and stimuli with negative valence indicate threatening situations, and lead to avoidance. Low-arousal and positive stimuli indicate safe situations and lead to approach. When a stimulus is positive and has a high-arousal level the approach-avoidance system receives conflicting information about whether or not to approach the stimulus. The same applies to stimuli that are low-arousal negative. Therefore, these types of stimuli are more difficult to process and are assumed to be processed more slowly. High-arousal negative and low-arousal positive stimuli, on the other hand, give unambiguous information about whether or not to approach the stimulus. These types of stimuli are thought to be processed easier and faster (Citron et al., 2014a; Robinson et al., 2004). Kousta et al. (2009), however, found in their LDT study that valence predicted the response latencies better than the arousal variable.

2.6.2 The influence of individual differences

As described above there are several word properties that affect visual word processing. Although in recent years many studies have controlled their stimulus material for these variables, there are still conflicting study results, as described above. One reason for these conflicting results may be that not just word properties but also individual differences between participants affect word processing.

Taroyan et al. (2020) conducted an LDT study with 24 university students. More than half of them showed a positivity bias, meaning they responded faster to words with positive valence than to negatively valenced words. The other participants demonstrated a negativity bias, they responded faster to negatively valenced words than to positive words. Interestingly, the authors found that the participants with a positivity bias showed faster lexical decision responses to all words than the participants with a negativity bias and had a greater capacity to regulate their emotions. Another LDT Study, which was conducted with 129 participants, examined the influence of personality traits on affective word processing. The results demonstrated that the traits approach temperament and extraversion were associated with a faster processing of pleasant words when compared to negative and neutral word stimuli (Borkenau et al., 2010). A Meta-analysis by Bar-Haim et al. (2007), which included 172 experimental studies, found that anxious individuals show an attentional bias towards threat-related stimuli. A study of 130 participants by Reuter et al. (2017) showed that individuals, who self-reported being sensitive to pain, associated words more intensively with pain than individuals, who reported being less sensitive to pain. The current mood state can also influence the processing of affective words (Sereno et al., 2015). In addition, visual attention influences the word length effect in LDTs, as it was calculated by Ginestet et al. (2019) using a Bayesian model of visual word recognition. Further, goal-directed behavior was linked to a slower processing of word stimuli that are related to fear (Mueller & Kuchinke, 2016). They also discovered a relationship between a processing advantage for happy-related word stimuli and the spontaneous eye-blink rate, which indicates dopamine levels. In sum, there are several individual differences that can affect word processing.

2.7 Reading comprehension

A definition of the process of reading comprehension is proposed as "simultaneously extracting and constructing meaning through interaction and involvement with written language" (Snow, 2002, p.11). Successful reading comprehension involves the establishment of a situation model, which means building coherent mental representations of the information obtained from the text (Van Dijk & Kintsch, 1983). To achieve a coherent mental representation, readers must monitor their understanding of the text (see Perfetti et al., 2005; Vorstius et al., 2013, for more information on comprehension monitoring).

Reasoning skills (Cutting & Scarborough, 2006), vocabulary depth and breadth (Cain & Oakhill, 2014) are, among others, important for good reading comprehension. In addition, working memory capacity is associated with adequate reading comprehension, according to a meta-analysis by Carretti et al. (2009). A meta-analysis by Daneman and Merikle (1996) analyzed 77 studies and concluded that working memory capacity has an important impact on the success of reading comprehension. Mind wandering, on the other hand, is counterproductive. It impairs reading comprehension because it distracts the reader (Reichle et al., 2010; Smallwood, 2011). In a study by Feng et al. (2013), it was found that in particular when reading texts with a higher level of difficulty, readers' minds wandered off more frequently.

A study by Arrington et al. (2014) found a significant direct effect of sustained attention on reading comprehension using path analyses. The control of eye movements was also found to be an essential component of the information processing during the reading process (Radach & Kennedy, 2013). In addition, the study of attention processes in eye movement research showed that the processing of written texts can involve processing more than one word at once (Radach et al., 2013). Individual differences also affect reading comprehension. For example, a study by Connor et al. (2015) reported that academic language skills predict comprehension monitoring development in fifth graders.

2.8 Linking meditation with word processing and reading performance

Meditation practice was reported to increase emotion regulation (Blanck et al., 2018; Chen et al., 2012; Hofmann et al., 2010), reduce mind wandering (Mrazek et al., 2012; Taraban et al., 2017)), improve focused attention (Chambers et al., 2008; Semple, 2010; see Lutz et al., 2008 for a review), and enhance working memory capacity (Bonamo et al., 2015; Mrazek et al., 2013; Quach et al., 2016).

These are all capabilities that are also linked with adequate and visual word processing and efficient reading comprehension. For example, the current mood state can influence the processing of affective words (Sereno et al., 2015). Arrington et al. (2014), reported a significant direct effect of sustained attention on reading comprehension. Working memory capacity was also associated with adequate reading comprehension recording to meta-analyses (Carretti et al., 2009; Daneman & Merikle, 1996). Mind wandering, on the other hand, impairs reading comprehension (Reichle et al., 2010; Smallwood, 2011).

However, direct effects of meditation on word processing and reading performance are still insufficiently studied. The existing studies on the impact of meditation practice on reading performance give inconclusive results. Clinton et al. (2018) and Mrazek et al. (2013) reported that meditation practice influenced reading comprehension positively. Linden (1973), on the other hand, found that an 18-week meditation intervention had no effect on participants' reading comprehension. A study by Benney et al. (2021) could not give conclusive results on the question of whether mindfulness meditation can enhance reading fluency.

It is important to examine if meditation techniques can enhance reading comprehension because meditation is relatively easy to learn and could be a useful tool to help people with reading difficulties. Further, it is important to explore to what extent external contexts like practicing meditation can alter the visual processing of written single words, since such individual differences might influence experimental studies on single word processing and valence ratings of affective word stimuli. The three experimental studies of the present doctoral thesis do not just explore a new field of research, they advance research because they address previous contradictory study results.

3 Research questions and aims of the three executed studies

3.1 First Study: Word recognition of adept Zen meditators

The main goal of the present doctoral thesis was to answer the question of whether meditation practice has an impact on visual word processing, which is a relatively unexplored area of research. The primary objective of study one was to examine whether a 90-minute meditation session would change the single-word processing in experienced Zen meditators. More precisely, it was examined whether a meditation session would affect response times to affective word stimuli in an LDT and the valence ratings to these words.

In the scientific literature, meditation practice was reported to alter the responses to emotional images (Desbordes et al., 2012; Ortner et al., 2007; Sobolewski et al., 2011). This is one of the reasons why it was important to study not only the influence of meditation on word processing in general but also in relation to emotional words. Another reason is that in everyday life we are very often confronted with words with affective content (e.g., when reading books, text messages, or the newspaper). If we want to know more about a possible influence of meditation on visual word processing, we most certainly need to consider also possible effects of meditation on emotional words.

In psycholinguistic studies, the LDT is a commonly used tool to examine the processing of single words (for example, Hofmann et al., 2009; Kuchinke et al., 2007; Lemhöfer & Radach, 2009; Oganian et al., 2016; Roelke et al., 2018; Westbury et al, 2013). Following the paradigm used by Hofmann et al. (2009), in the first study, adept Zen meditators and gender- and age-matched control participants performed an LDT with low-arousal positive and negative words, as well as, neutral and high-arousal negative words. Participants were then asked to rate the valence of the words which they had encountered during the LDT. Afterwards, the Zen group practiced a 90-minute Zen meditation, while the control group watched an emotionally unarousing nature documentary for the same amount of time. Subsequently, both groups executed again the LDT and the valence rating task with different word stimuli. In order to be comparable to the reference study by Hofmann et al. (2009; *n* = 20), each group consisted of 20 participants (see Figure 3 for study design).

In summary, the first study addressed the following research questions:

- Does a meditation session alter the processing of visual affective word stimuli in expert Zen meditators?

In particular:

- Does a meditation session lead to faster responses to low- and high-arousal negative, low-arousal positive, and neutral word stimuli in an LDT (since meditation increases focusses attention; Sumantry and Stewart, 2021)?
- Does a meditation session lead to differential emotion effects during lexical decisions?
- Does meditation practice lead to more neutral valence ratings of affective word stimuli (since meditation enhances emotion regulation; Blanck et al., 2018)?

Further research questions:

Were the following study results of Hofmann et al. (2009) replicated?

- High-arousal negative words were processed faster than neutral words.
- Positive words were processed faster than neutral words.
- Low-arousal negative words were processed slower than neutral words.

Study 1: Study design

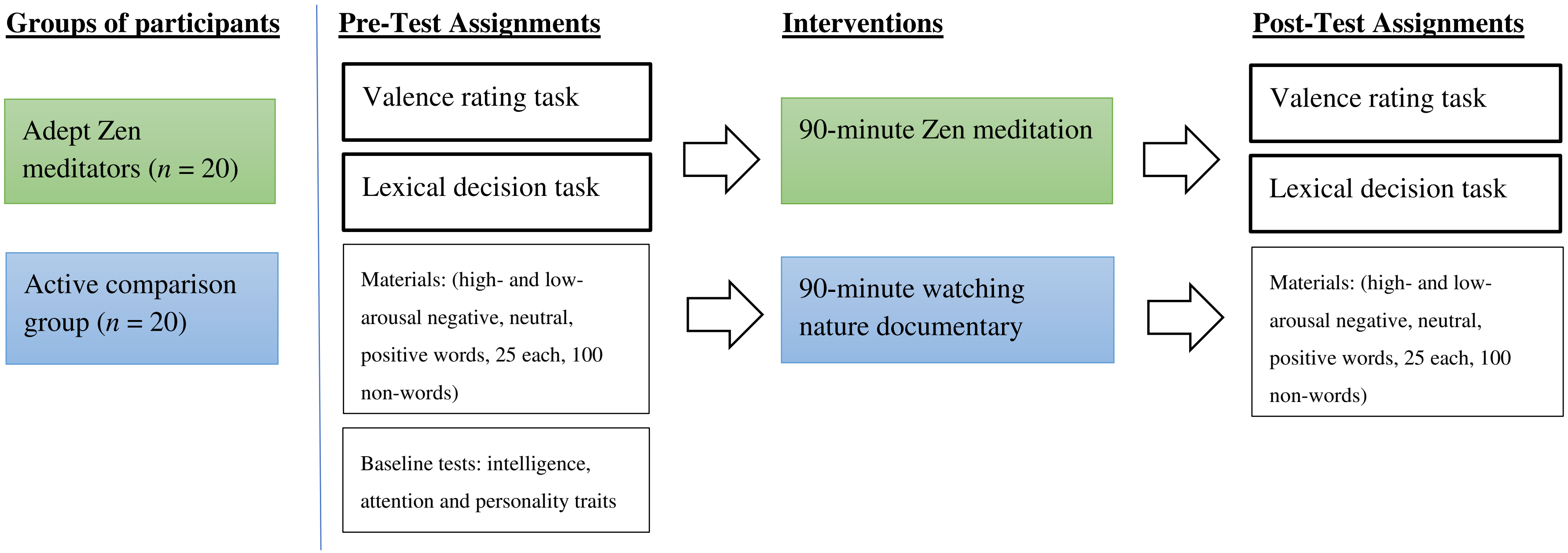

Figure 3. Study 1, diagram of the pretest-posttest comparison group design

3.2 Second study: Word recognition of meditation novices

The first study presented evidence that a meditation session can lead to globally faster response times in an LDT and to more neutral valence ratings of affective word stimuli in adept Zen meditators. Regarding study two, these results led to the question of whether meditation novices would show similar alterations in word processing after a meditation class.

Different meditation styles can have different effects. For example, mindfulness meditation has been associated with better attentional capacities (Chambers et al, 2008; Valentine & Sweet, 1999). In addition, mindfulness meditation was reported to regulate negative affect (Sears & Kraus, 2009), depression (Grecucci et al., 2015; Tang et al., 2007), stress (Goyal et al., 2014), and anxiety (Hofmann et al., 2010; Tang et al., 2007). Loving-kindness meditation, on the other hand, was reported to increase positive emotions (Zeng et al., 2015). Therefore, it was of interest to determine whether different meditation techniques could have different effects on word processing.

Study two was designed as a longitudinal study. Similar to study one, the participants in study two conducted an LDT and a valence rating task. In study two, the stimulus material from study one (originally from Hofmann et al., 2009) was used and extended to a total of 400 words and 400 altered words (non-words) while controlling for emotional valence, arousal, word frequency, number of orthographic neighbors, imageability, number of letters, mean bigram frequency (type), and mean bigram frequency (token). Starting from the following week, participants took part in one of three classes: mindfulness meditation, loving-kindness meditation, or a study group. All courses lasted for seven weeks. After the completion of the courses, the participants took part in the LDT and the valence rating task, again. Word stimuli were changed compared to the pre-test. In addition, participants conducted a brief assessment of their current mood states before and after the meditation and control interventions. Every group consisted of 13 participants. According to the formula of Westfall et al. (2014), a sample size of n = 11.8 participants per group was sufficient to achieve a mean effect size of d = 0.5 and a power of 0.8 when using 400 word stimuli per participant (see Figure 4 for study design).

In short, study two addressed the following research issues:

- Does meditation alter the word processing of meditation novices?
- Can the results of the first study be replicated in a study with meditation novices?

In particular:

- Lead mindfulness and loving-kindness meditation to faster responses to affective and neutral word stimuli in an LDT than at baseline?
- Lead mindfulness and loving-kindness meditation to differential emotion effects during lexical decision?
- Lead mindfulness and loving-kindness meditation to more neutral valence ratings of affective and neutral word stimuli than at baseline?
- Do different meditation techniques have different influences on response times in the LDT?
- Do different meditation techniques have different influences on the valence ratings of the affective words?
- Does emotion regulation mediate effects of meditation practice on response times in the LDT and on valence ratings of affective word stimuli?
- Are there differences in word processing between expert meditators and meditation novices?

Further research questions:

Were the following study results of Hofmann et al. (2009) replicated?

- High-arousal negative words were processed faster than neutral words.
- Positive words were processed faster than neutral words.
- Low-arousal negative words were processed slower than neutral words.

Study 2: Study design

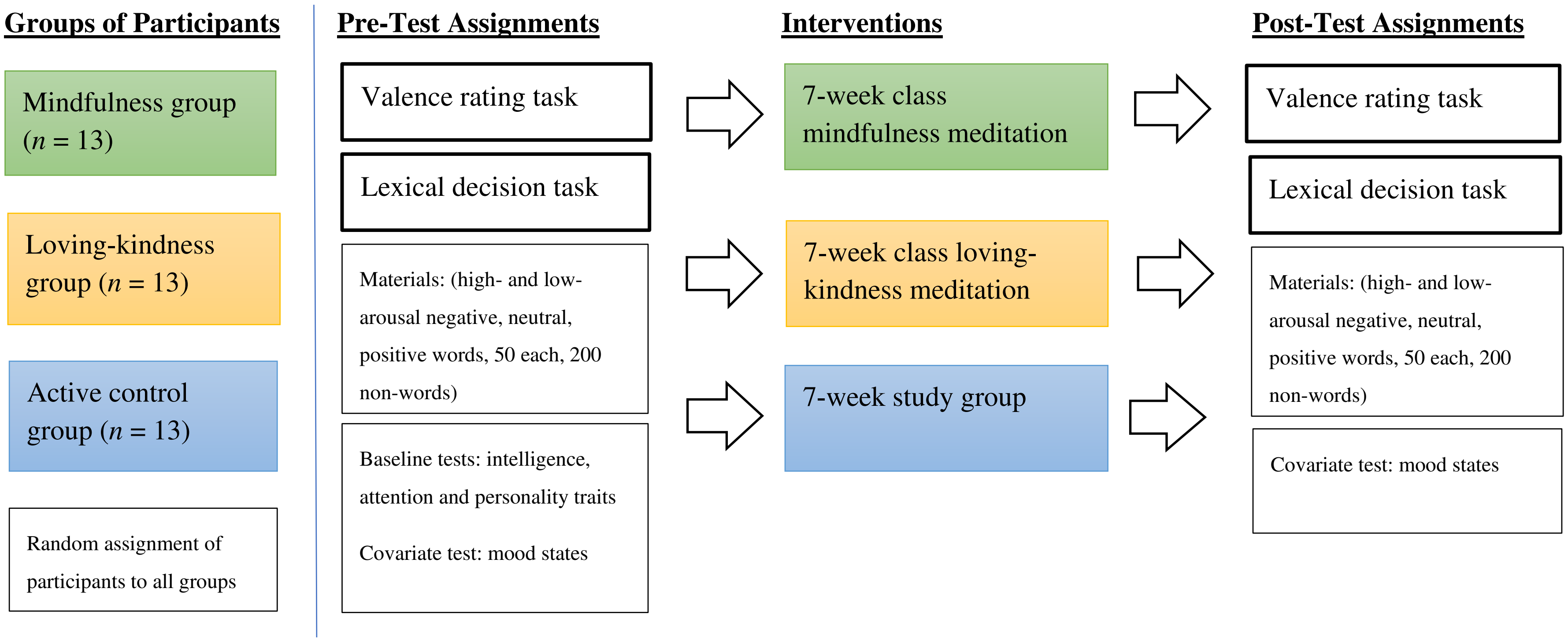

Figure 4. Study 2, diagram of the longitudinal study design

3.3 Third study: Reading performance of meditation novices

The first two studies presented evidence that meditation can lead to globally faster responses in an LDT and to more neutral valence ratings of affective word stimuli. The results were found for both, experienced meditators and novice meditators as well as for Zen, mindfulness, and loving-kindness meditation.

These findings led to the question of whether not only words but also texts would be processed faster after a meditation intervention. This question was examined in study three. Further, the third study aimed at assessing whether meditation practice has an impact on reading comprehension. There are only a few studies on this topic in the scientific literature and they show inconclusive results. Clinton et al. (2018) and Mrazek et al. (2013) reported that meditation practice has a positive impact on reading comprehension. Linden (1973) on the other hand, did not find a significant effect of an 18-week meditation class on reading comprehension. A study by Benney et al. (2021) could not give conclusive results on the question of whether a mindfulness intervention could enhance reading fluency.

In study three, participants performed a reading comprehension and reading speed test before and after a 6-week mindfulness meditation course or control intervention. The effects of meditation on focused attention, emotion regulation, and personality traits were also assessed and taken into account as possible mediator variables. The sample size of $n = 52$ is comparable to a reference study by Mrazek et al. (2013; $n = 48$), which reported effects of meditation practice on reading comprehension (see Figure 5 for study design).

Briefly summarized, study three regarded the following scientific questions:

- Does mindfulness meditation affect reading performance?

In particular:

- Does meditation practice alter the reading speed of meditation novices?
- Does meditation alter the reading comprehension of meditation novices?
- Does meditation have an impact on focused attention, emotion regulation, and personality traits?
- Do emotion regulation, focused attention, and personality traits mediate possible effects of meditation on reading comprehension and speed?

Study 3: Study design

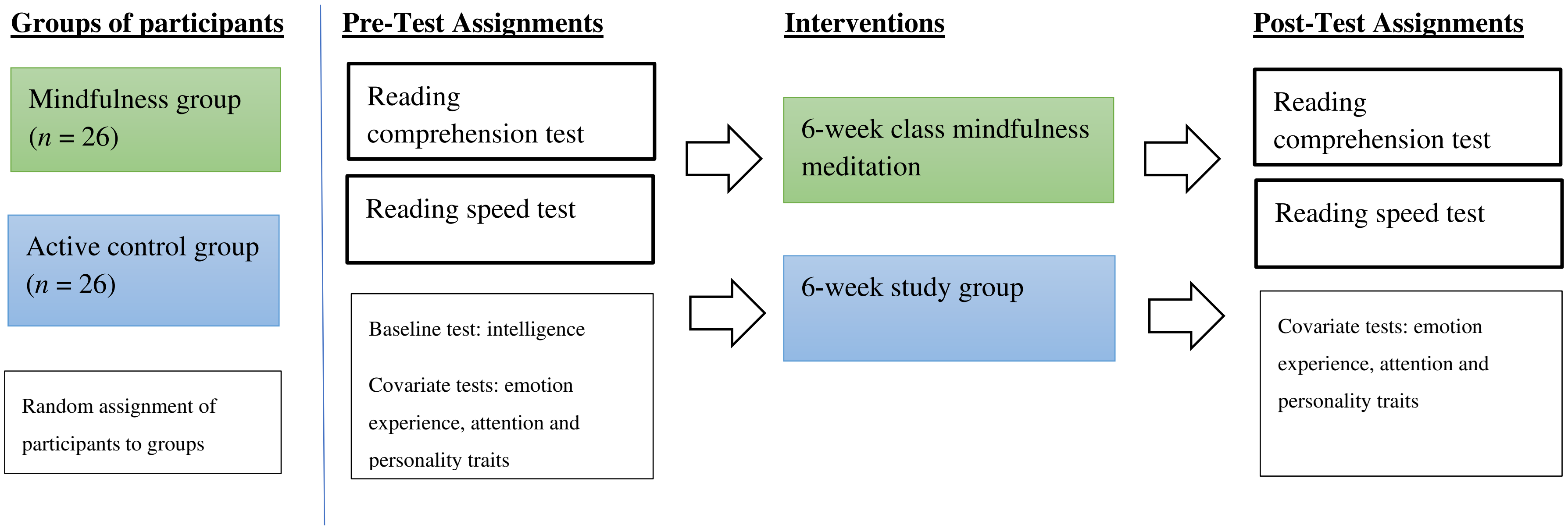

Figure 5. Study 3, diagram of the longitudinal study design

4 Study 1: Zen meditation neutralizes emotional evaluation, but not implicit affective processing of words

4.1 Citation and author contributions

Title: Zen meditation neutralizes emotional evaluation, but not implicit affective processing of words.

Authors: Lusnig, Larissa, Radach, Ralph, Mueller, Christina J., & Hofmann, Markus J.

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Text format, tables, figures and citation style of the manuscript are adapted to the specifications of the journal. For enhanced readability tables and figures are included in the main text.

Author contributions:

Larissa Lusnig: Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Visualization, Writing – original draft, Writing – review and editing.

Ralph Radach: Conceptualization, Investigation, Writing – original draft, Writing – review and editing.

Christina J. Mueller: Roles Conceptualization, Writing – review and editing.

Markus J. Hofmann: Conceptualization, Data curation, Formal analysis, Funding acquisition, Writing – original draft, Writing – review and editing.

4.2 Published manuscript

Zen meditation neutralizes emotional evaluation, but not implicit affective processing of words

Larissa Lusnig, Ralph Radach, Christina J. Mueller, Markus J. Hofmann

Abstract

There is ample evidence that meditation can regulate emotions. It is questionable, however, whether meditation can down-regulate sensitivity to emotional experience in high-level cognitive representations such as words. The present study shows that adept Zen meditators rated the emotional valence of (low-arousal) positive and (high- and low-arousal) negative nouns significantly more neutral after a meditation session, while there was no change of valence ratings after a comparison intervention in the comparison group. Because the Zen group provided greater "openness to experience" and lower „need for achievement and performance" in the "Big Five" personality assessment, we used these scores as covariates for all analyses. We found no differential emotion effects of Zen meditation during lexical decision, but we replicated the slow-down of low-arousal negative words during lexical decision in both groups. Interestingly, Zen meditation elicited a global facilitation of all response times, which we discuss in terms of increased attentional resources after meditation.

Keywords: meditation, emotional valence, arousal, emotion regulation, lexical decision, LDT

Introduction

The scientific interest on meditation has grown substantially over the last two decades, as has our understanding of its neurocognitive mechanisms in emotion regulation (for reviews see [1,2]). While it is well known that behavioral and neural responses to emotional images can be attenuated by meditation [3–5], it is less clear whether meditation also affects higher-level emotional representations such as words. Therefore, the aim of the present study was to examine whether the meditation practice of adept meditators has an impact on emotional valence ratings of word stimuli, as well as on emotional valence effects in visual word recognition [6,7].

Meditation in attention and emotion regulation

Meditation is the mental practice of increasing attention and calmly observing all experiences in the present moment. Zen meditation is similar to mindfulness meditation [8] and both styles fall under the category of open monitoring meditation. In open monitoring meditation, the practitioner maintains consistent attention and does not focus on a precise thought or object [9]. In the Japanese Soto Zen tradition, which first developed in the early thirteenth-century, meditation usually consists of seated meditation phases (Zazen) and short phases of walking meditation (Kinhin). Practitioners are seated upon a cushion (Zafu) and are facing the wall. During Zazen, meditators keep their eyes half open and the gaze does not focus on any object [10,11].

The achievement of a readiness of mind, which is a smooth, imperturbable and effortless way of thinking, is described by spiritual Zen literature as an aim of meditation. Practitioners are supposed to be "ready for observing things, and to be ready for thinking". Concentration should always be present in the meditators mind [12]. In fact, meditation practice can facilitate practitioners' ability to maintain focused attention [13–16]. For example, expert meditators are able to slow down binocular rivalry switching after meditation [17] and demonstrate a decrease of thought distraction and an increase of the present focus [18].

Thoughts, which naturally cross the mind during Zen meditation, are not judged as "good" or "bad" by the meditator. The existence of these thoughts is noticed and then the practitioner lets them pass by [11]. This practice seems to have a positive effect on the ability to regulate negative emotions. Practitioners can regulate negative emotions such as stress [19], anxiety [16,20] or depression more easily [16,21].

Several studies have demonstrated that meditators show a reduced reactivity to emotional images: Desbordes and colleagues [3] investigated the influence of a mindfulness meditation training that was exercised for two hours a week over a period of eight weeks. They found a decrease in amygdala activation during the presentation of emotional images, thus suggesting a decrease of their emotional impact [22]. Moreover, meditators and comparison subjects showed differences in the late positive potential (LPP) between affective and neutral images [5]. LPP amplitudes over frontal scalp regions in response to negative pictures were greater in the comparison group compared to meditation practitioners. Usually, affective images, in comparison to neutral images, provoke greater LPP amplitudes. A third example showing that experienced meditators were less affected by negative images was provided by Ortner and colleagues [4]. They found that participants with more mindfulness meditation experience presented smaller interference from emotional pictures and reported higher psychological well-being. These results suggest that mindfulness meditation can attenuate the emotional reactivity to affective images.

Longitudinal studies also show that meditation interventions can regulate emotions. In a study by Hölzel and colleagues [23] mindfulness meditation practice led to an increase in brain gray matter density in the left hippocampus - a structure associated with emotion regulation [24]. Finally, Chau and colleagues [25] showed that a sample of older people rated negative and positive images more neutral after a compassion meditation intervention. Though the impact of meditation on emotional picture evaluation has been well explored, to our knowledge there is no study investigating the influence of meditation on affective word processing.

Emotional word recognition

To determine the emotional impact of word stimuli, a standard practice is to collect valence ratings [26–29]. Participants are exposed to a word stimulus and explicitly judge the emotional valence on a 7-point scale ranging from -3 (very negative) through 0 (neutral) to +3 (very positive). These ratings are taken to select stimulus materials for visual word recognition studies. In the lexical decision task (LDT), emotional evaluation is not explicitly required, but occurs implicitly: Letter strings are displayed to participants, who have to decide under time pressure if the strings are words or not [30,31]. While the influence of stimulus properties (like word frequency, sublexical frequency measures, length, valence and many more) on single word recognition is well examined [32–35], little research has focused on the question whether interindividual differences have an impact on single word recognition. For instance, Siegle and colleagues [36] examined the influence of depression on word recognition. Dysphoric and non-dysphoric subjects conducted a valence identification task, in which words were to be classified as negative, neutral or positive, as well as an LDT. In comparison to non-dysphoric participants, dysphoric subjects identified the valence of positive words significantly slower than the valence of negative words. In the LDT, dysphoric participants recognized negative words slower than neutral words. Non-dysphoric subjects responded significantly faster to negative compared to neutral words. Baldwin and colleagues [37] examined whether subjects' self-confidence could influence their RTs to emotional words. Secure participants were faster than insecure subjects to recognize words which expressed positive interpersonal outcomes. In contrast, insecure subjects identified words expressing negative interpersonal outcomes faster. In sum, there are several studies showing that interindividual differences have an impact on emotion effects in the lexical decision task [38]. There is no study, however, that addresses the emotion-regulation capabilities of meditators in word stimuli.

The present study

The present work examined whether Zen meditation has an influence on the processing of single words. Adept Zen practitioners and age- and gender-matched comparison subjects conducted an LDT with positive, neutral, and low- and high-arousal negative word stimuli before and after a meditation or comparison intervention. After the LDTs, they rated the valence of the respective words. We used the stimulus set of Hofmann and colleagues [6]. For the comparison group, we expected no difference between the valence ratings before and after the comparison intervention. We also assumed that, if the meditation session has an impact on emotion regulation in the Zen group, the meditation treatment might act to decrease the emotional valence ratings.

For the LDT, we expected to replicate the results of Hofmann and colleagues [6] in the comparison group. They found that low-arousal negative words were processed slower than neutral words. Responses to positive and high-arousal negative words were faster than the responses to neutral words. We also follow these authors in terms of sample size (N = 20; see also [26], for valence ratings with the same sample size). For the meditation group, the critical question was whether the meditation treatment had an influence on the emotional experience as reflected in outcome measures of the LDT. An impact on emotion regulation by meditation would be evident in diminished effects of word affectivity on outcome measures of the LDT after meditation as compared to before meditation. If the meditation session, in contrast, has an unspecific effect on attention capacities, generally faster response times may be observed after, as compared to before meditation. To control interindividual differences between both groups irrespective of meditation, we further assessed concentration capacity, intelligence and personality traits of all participants to use them as potential covariates.

Method

Participants

The Zen meditation group consisted of twenty German native speakers (9 female, 19–53 years of age, mean age = 33.3, SD = 11.13). They were recruited at local meditation centers in North Rhine-Westphalia, Germany and had a meditation experience of M = 7.9 years (0.5–28 years, SD = 4.9 years). The weekly meditation practice amounted to M = 4.3 hours (SD = 1.6 hours). The average age and gender of twenty German native speakers was matched for the comparison group (9 female, 18–56 years of age, mean age = 34.5, SD = 11.26). Participants of the comparison group were recruited at the University of Wuppertal or via online advertisements. All subjects of the comparison group reported no prior meditation or yoga experience. The subjects received course credit or money and sweets for their participation. All subjects of the present study gave informed written consent.

This work was carried out in accordance with the ethical standards provided by the Declaration of Helsinki and the German Society for Psychology (DGPs). The Ethics Committee of the University of Wuppertal granted approval for our study.

To take into account interindividual differences in concentration capacity, intelligence and personality traits all subjects conducted three covariate tests. First, participants completed the d2-Revision test, which measures concentration and attention ability. This time-pressured assessment requires participants to cross out the letter “d” with two marks and ignore similar looking distractors in a continuing row of characters [39]. Second, participants were asked to discriminate increasingly complex target words from nonword distractors in the Multiple-Choice Vocabulary Intelligence Test (MWT-B) [40]. Third, participants completed the Big Five personality test (B5T). Originally the test had five scales “neuroticism” (Cronbach’s alpha, $\alpha = .90$), “extraversion” ($\alpha = .87$), “conscientiousness” ($\alpha = .77$), “agreeableness” ($\alpha = .76$) and “openness to experience” ($\alpha = .76$). We used the revised version, which has been extended by the three basic requirements "need for safety and peace" (α = .84), "need for power and influence" (α = .78) and "need for achievement and performance" (α = .82) [41].

Materials

Our stimulus set was composed of 200 German nouns and 200 nonwords. We used the stimulus set from Hofmann and colleagues [6], including the stimulus conditions of high-arousal negative, low-arousal negative, neutral and (low-arousal) positive words. The Berlin Affective Word List Reloaded (BAWL-R) provided too few high-arousal positive nouns (see Fig 1 in [26]) to generate this condition while likewise matching for nine other variables known to affect word recognition (cf. [6]). To prevent undesired influences of word properties, words were carefully matched for emotional valence, arousal, imageability, number of letters, number of syllables, word frequency, number of orthographic neighbors, mean letter frequency (type), mean letter frequency (token), mean bigram frequency (type) and mean bigram frequency (token) (see Table 1 in [6], for stimulus characteristics). The 200 nonwords were built by replacing the vowel of a word with either another vowel or with a consonant. To generate two comparable stimulus sets for the pre- and post-tests, the stimuli of the experimental conditions were divided into subset A and subset B. We conducted 4 x 2 ANOVAs for the control variables to make sure that the subsets did not differ with respect to the control variables (all F's < 1). In total, every subset consisted of 100 words and 100 nonwords. Subset A and B were used as pre- and post-test in half of the participants and for the other half vice versa.

Procedure

Pre-test. After addressing the interindividual differences (see Participants for more details on psychometric assessments), participants started with the main experiment. They sat in front of a 17-in. color monitor (70 Hz). The laboratory was dimly illuminated. Eye-monitor distance was about 65 cm. Subjects were instructed to press a button with the left index finger for nonwords and another button with the right index finger for words. All participants were instructed to respond as fast as possible without reducing accuracy. Five practice stimuli preceded each LDT. Stimuli were displayed on a white screen in black uppercase letters (Times New Roman font, 20 pt). The software PsychoPy was used for stimulus presentation (version 1.82.01, [42]). Stimulus order was pseudorandomized, such that no more than three words or nonwords appeared consecutively. In each trial, a fixation cross (+) was displayed for 700 ms, then the stimulus was shown for 1,000 ms. To put the participants under severe time pressure, they were required to respond within this time window (c.f.[6]). Then, a blank screen was presented for 500 ms, followed by a mask (#####) for 1,500 ms (see Fig 1). After a break of approximately five minutes, participants performed a valence rating on the words presented in the LDT. The seven-point rating scale ranged from -3 to 3 (-3 = very negative, 0 = neutral, 3 = very positive).

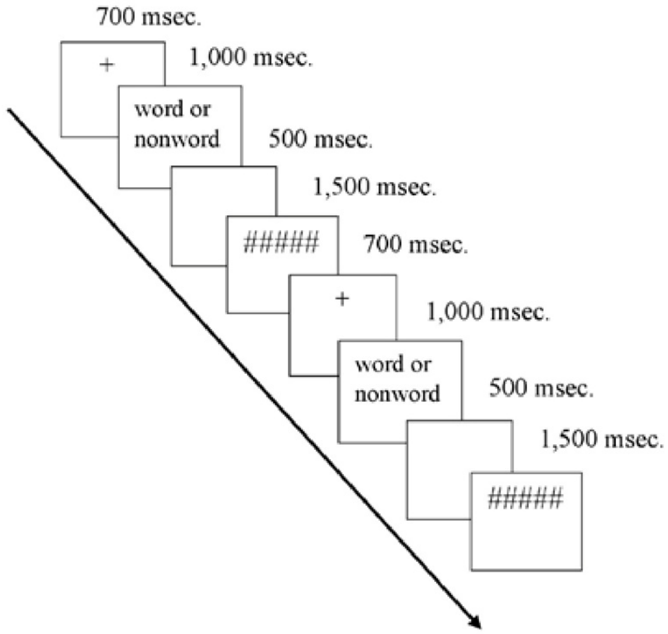

Fig 1. Experimental timeline for the LDT experiments.

Meditation and comparison interventions. The 1.5-hour meditation session consisted of two 25-minute seated Zen-Meditations (Zazen) followed by 5-minute walking Zen-Meditations (Kinhin). Additionally, spoken mantras were recited for approximately 30 minutes, for instance the heart sutra representing the Buddhist principle of emptiness [43]. The participants of the comparison group watched a 90-minute interesting but calm and non-arousing documentary landscape movie called “Unsere Erde” (“Our Earth”, [44]).

Post-test. After the meditation or comparison intervention, subjects participated in the post-test of the experiment. The LDT procedure was the same as for the pre-test.

Data analyses

From the valence rating task, we obtained answers on a seven-point rating scale from -3 to 3. We recorded the RTs of the correct answers from the LDT. For the statistical analyses of the RT data and for the valence-rating data, we calculated linear mixed effects models

(LMEs) using the lmer function from the lme4 library (version 1.1–14, [45]) in the statistical software environment R [version 3.4.2, http://cran.r-project.org]. An LME analysis allows considering subject and item variance in a non-hierarchical approach [46]. We fitted „subjects" and „items" as random effects, and "group" (meditators/comparison), "time" (before/after) and "emotional valence" (high-arousal negative/low-arousal negative/positive words) as fixed effects. For the representation of the fixed effects, we used effects-coding; high-arousal negative, low-arousal negative, and positive words were contrasted against neutral words. Separate LME analyses were calculated for the Zen and for the comparison group to examine significant interactions. Normality of the residuals was examined using qqplots and the empirical distributions. For the valence-rating model, data points outside the range of -3 and 3 SD of the residual error of the model were rejected from the analyses, which eliminated less than 1% of the data. RTs were log-transformed. We report p-values based on the Satterthwaite approximation using the lmerTest package (version 2.0–36, [47]).

Results

Interindividual differences

We tested participants of both groups for significant differences in intelligence, concentration capacity and personality traits to control the influence of these traits on RT and valence rating results (cf. Table 1). Because "openness to experience" was higher and "need for achievement and performance" was lower in the Zen meditation group, we inserted them as covariates in the valence rating and LDT analysis.

Table 1. Statistical group differences, mean values and standard deviations of covariate tests.

Covariate Test	Statistical Group Differences	Zen Group		Comparison group	
Big Five personality test		*M*	*SE*	*M*	*SE*
Neuroticism	t(38) = -0.71, p = 0.48	4.10	0.32	4.40	0.28
Extraversion	t(38) = 0.20, p = 0.84	5.80	0.34	5.70	0.36
Conscientiousness	t(38) = 0.39, p = 0.70	4.75	0.35	4.55	0.37
Agreeableness	t(38) = 0.15, p = 0.88	5.25	0.39	5.15	0.53
Need for Safety and Peace	t(38) = 1.74, p = 0.09	4.30	0.31	5.15	0.38
Need for Power and Influence	t(38) = -1.90, p = 0.06	4.55	0.36	5.35	0.22
Openness	t(38) = 3.36, p = 0.01	6.35	0.36	4.45	0.44
Need for Achievement and Performance	t(38) = -2.35, p = 0.03	4.00	0.33	5.20	0.39
Concentration Capacity Test (d2-R)		*M*	*SE*	*M*	*SE*
Number of Processed Target Objects	t(38) = -0.11, p = 0.92	168.25	6.43	169.20	6.39
Concentration Capacity	t(38) = 1.04, p = 0.31	150.78	4.61	141.20	7.99
Percentage of Errors	t(38) = -1.36, p = 0.18	11.86	1.71	15.59	2.14
Intelligence Test (MWT-B)		*M*	*SE*	*M*	*SE*
	t(38) = -0.13, p = 0.90	24.95	0.92	25.10	0.73

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Valence rating and lexical decision data

The overall analysis of the valence rating and the lexical decision data revealed significant main effects of “time” and significant interactions of “time” and “group” (see Table 2 for the overall analysis). In the valence rating analysis, “high-arousal negative” and “low-arousal negative”, as well as “positive” words provided significant two-way interactions with “time”, and three-way interactions with “time” and “group”. Moreover, we found a significant main effect of “high-arousal negative” words in the rating data. In the lexical decision analysis, we found a significant main effect of “low-arousal negative” words.

Table 2. Estimates of the regression coefficients, their standard errors, t-values and p-values for the valence and the LDT experiments in the overall analyses.

	Valence Ratings				Lexical Decision Task			
	B	**SE**	**t**	**p**	**B**	**SE**	**t**	**p**
Time	0.16	0.026	5.99	0.001 ***	-0.06	0.004	-13.70	0.001 ***
Group	-1.12	0.181	-0.95	0.319	0.03	0.549	0.06	0.956
High-arousal negative	-1.66	0.845	-1.97	0.049*	-0.01	0.008	-0.41	0.685
Low-arousal negative	-1.31	0.841	-1.56	0.118	0.02	0.009	1.97	0.049*
Positive	1.07	0.843	1.27	0.206	-0.01	0.009	-1.34	0.182
Time:Group	-0.15	0.037	-3.89	0.001***	0.05	0.006	8.92	0.001***
Time:High-arousal negative	0.25	0.046	5.58	0.001***	-0.01	0.008	-1.11	0.266
Group:High-arousal negative	1.16	1.178	0.98	0.325	-0.01	0.008	-0.45	0.649
Time:Low-arousal negative	0.23	0.046	5.04	0.001***	0.01	0.007	0.89	0.374
Group:Low-arousal negative	0.99	1.176	0.84	0.401	0.01	0.007	1.38	0.168
Time:Positive	-0.36	0.046	-7.87	0.001***	-0.01	0.007	-0.02	0.986
Group:Positive	1.24	1.176	1.06	0.291	0.01	0.007	0.34	0.732
Time:Group:High-arousal negative	-0.28	0.065	-4.33	0.001***	-0.01	0.011	-0.26	0.822
Time:Group:Low-arousal negative	-0.19	0.065	-3.01	0.003**	-0.01	0.011	-0.66	0.508
Time:Group:Positive	0.36	0.065	5.52	0.001***	-0.01	0.011	-0.37	0.713
Openness	0.01	0.023	0.46	0.647	0.06	0.138	0.40	0.691
Need for Achievement and Performance	-0.03	0.026	-1.18	0.244	0.01	0.025	0.57	0.568

"***" = $p < 0.001$

"**" = $p < 0.01$

"*" = $p < 0.05$

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To resolve the interactions with the factor “group”, we fitted separate LMEs for the Zen and the comparison group (cf. Table 3). Here, we found significant valence rating and lexical decision effects of “time” for the Zen group, but not for the comparison group. This indicates that the meditation session had an effect on meditators, but the comparison intervention did not affect our comparison group.

Table 3. Estimates of the regression coefficients, their standard errors, t-values and p-values for the LDT in the Zen and comparison group.

	Valence Ratings				**Lexical Decision Task**			
	B	**SE**	**t**	**p**	**B**	**SE**	**t**	**p**
Zen Group								
Time	0.15	0.026	5.91	0.001***	-0.06	0.004	-14.04	0.001***
High-arousal negative	-1.84	0.838	-2.19	0.028*	-0.01	0.008	-0.42	0.675
Low-arousal negative	-1.51	0.835	-1.81	0.071	0.02	0.008	1.99	0.046*
Positive	0.88	0.837	1.05	0.295	-0.01	0.007	-1.47	0.141
Time:High-arousal negative	0.25	0.045	5.48	0.001***	-0.01	0.007	-1.14	0.252
Time:Low-arousal negative	0.23	0.045	5.14	0.001***	0.01	0.007	1.07	0.284
Time:Positive	-0.36	0.045	-7.85	0.001***	-0.01	0.007	-0.11	0.917
Openness	0.07	0.040	1.71	0.104	0.07	0.228	0.29	0.768
Need for Achievement and Performance	-0.04	0.043	-0.94	0.361	0.01	0.245	0.03	0.975
Comparison Group								
Time	0.01	0.027	0.39	0.691	-0.01	0.004	-1.09	0.275
High-arousal negative	-0.28	0.861	-0.32	0.748	-0.01	0.009	-0.69	0.489
Low-arousal negative	-0.09	0.856	-0.12	0.915	0.03	0.009	2.94	0.004**
Positive	2.55	0.859	2.97	0.003**	-0.01	0.009	-0.99	0.321
Time:High-arousal negative	-0.02	0.046	-0.34	0.735	-0.01	0.007	-1.51	0.131
Time:Low-arousal negative	0.04	0.046	0.83	0.407	0.01	0.007	0.09	0.922
Time:Positive	-0.01	0.046	-0.27	0.791	-0.01	0.007	-0.47	0.639
Openness	-0.03	0.024	-1.13	0.271	0.05	0.178	0.26	0.801
Need for Achievement and Performance	-0.03	0.027	-1.01	0.270	0.01	0.026	0.48	0.632

"***" = $p < 0.001$

"**" = $p < 0.01$

"*" = $p < 0.05$

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In the valence rating analysis of the Zen group, there were significant two-way interactions of "time" with "positive", "high-arousal negative" and "low-arousal negative" words. Fig 2 shows that emotional valence ratings became more neutral after the Zen meditation session. When examining the main effect of high-arousal negative words from the overall analysis in detail, we found no significant effect in the comparison group, but a significant effect in the Zen group. We speculate that this in part results from the "neutral" words, which were rated slightly positive in the Zen group and slightly negative in the comparison group, resulting in a smaller difference (cf. Fig 2). This negativity in ratings for neutral words may also account for the effect of positive valence in the comparison group.

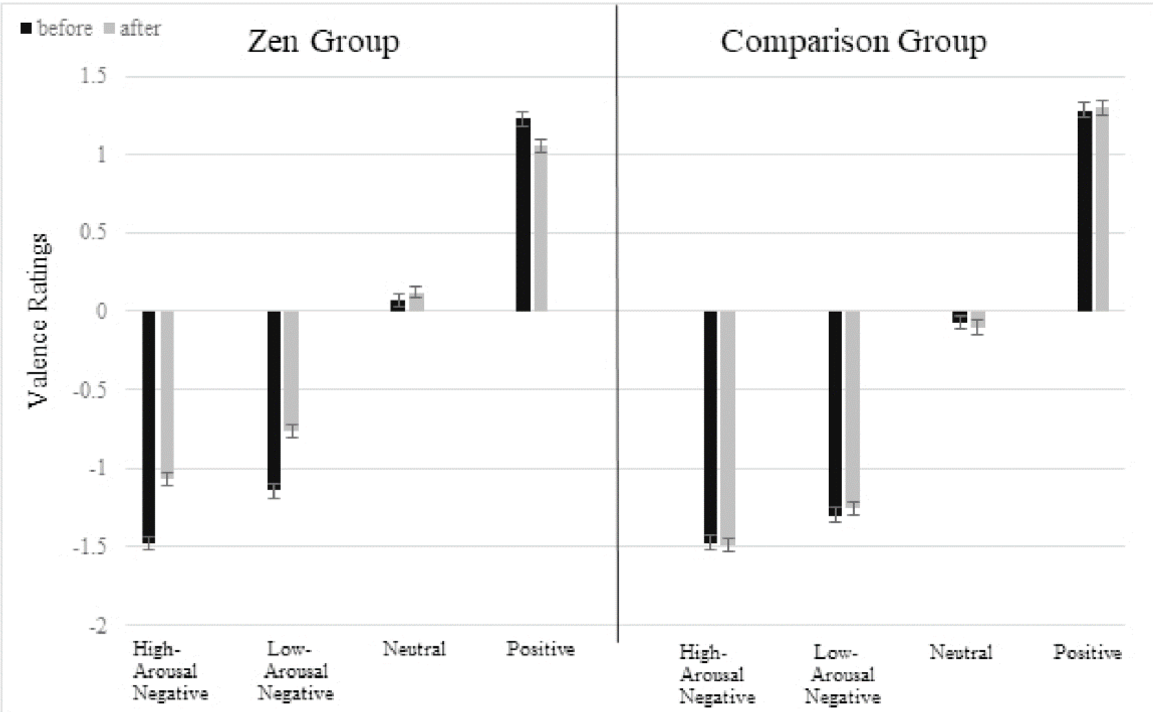

Fig 2. Valence rating results. Error bars indicate standard errors.

Fig 3 shows that the lexical decision effect of "time" in the Zen group resulted from an unspecific facilitation due to the meditation session. The descriptive data might appear to suggest that meditators demonstrated, before the interventions, generally slower RTs than comparison subjects did. However, response times do neither differ significantly between groups at baseline ($b = -0.06$, $SE = 0.481$, $t = -0.12$, $p > 0.05$), nor after the interventions ($b = -0.01$, $SE = 0.486$, $t = -0.01$, $p > 0.05$). Finally, the lexical decision main effect of low-arousal negative words was replicated in the Zen and in the comparison group, respectively (cf. [6]). To assure the robustness of our results, we computed the statistical models without any covariates. All significant effects remained the same. When we calculated the analysis with the marginally significant covariates “need for power/influence” and “need for safety/peace” significant effects did not change either.

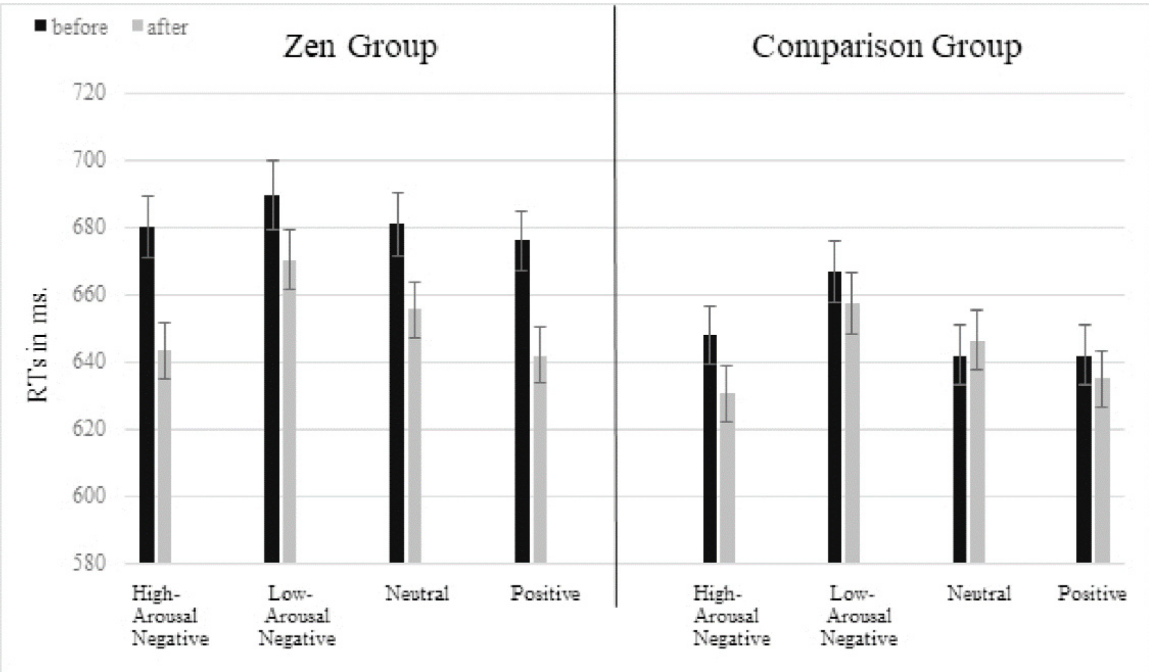

Fig 3. RTs in the lexical decision experiment. Error bars indicate standard errors.

Discussion

Our sample of Zen meditators showed larger “openness to experience” and less “need for achievement and performance” than the comparison group. In order to control these traits’ effects on word processing outcomes, we included them as covariates in the analyses. After a 90-minute Zen meditation, valence ratings were more neutral than before, while the comparison intervention elicited no change of valence ratings. Even though the explicit evaluation of words was affected by meditation, we found no effects of meditation in the lexical decision task, where affective evaluation was not explicitly required. Rather, we were able to replicate the effect of low-arousal negative words during lexical decision in both groups [6]. Finally, word recognition was accelerated by Zen meditation compared to performance before the meditation intervention. The comparison group showed no significant differences in lexical decision RTs after comparison intervention.

Valence rating experiment

While previous studies revealed that meditation can reduce the emotional impact of picture stimuli [e.g. 3,22], the present study shows that meditation also has a substantial effect on emotional word processing. Adept meditators rated the valence of high- and low-arousal negative and low-arousal positive words as more neutral after the meditation intervention. Emotion regulation, elicited by the meditation intervention, could be an explanation for the neutralized valence ratings. During Zen meditation, practitioners train not to judge thoughts on a positive-negative scale [11]. In fact, several studies show that meditation practice can help to regulate practitioners' emotions. Tang and colleagues [16] demonstrated lower depression and anger scores as well as a significant decrease in stress-related cortisol after 5 days of meditation training. Meditation practice can lead to a decreased sensation of anxiety [see 20, for a review] and stress [see 19, for a review]. Moreover, after an 8-week mindfulness meditation training, the amygdala of meditators was less activated during the display of emotional images than before the meditation training [3]. Our findings contribute to the discussion of a role of meditation in emotion regulation by demonstrating a potential mechanism: Meditation may help to down-regulate emotions and dampen the emotional assessment of word stimuli.

While we report neutralized emotional states being associated with more neutral valence ratings, Kanske and Kotz [48] found in a complementary study that increased emotional states, such as anxiety and depression, increased emotional valence ratings of words: In their study, subjects with greater depression scores displayed more negative valence ratings of negative and positive words. Participants with higher anxiety scores rated negative words as more arousing and more negative, thereby corroborating the notion of emotional states influencing stimulus valence ratings.

Lexical decision task

While we found emotion regulation effects in the explicit valence rating task, there was no evidence suggesting that meditation also changed the implicit effects of affective word features in the LDT. We replicated the results of Hofmann and colleagues [6] in both, the experimental and the comparison groups, indicating that low-arousal negative words are processed generally slower than neutral words. We were not able to replicate their effects that high-arousal negative and (low-arousal) positive words were processed faster than neutral words, even though there was a tendency in this direction after the meditation and comparison intervention in both groups. Electrode preparation in the EEG study by

Hofmann and colleagues' [6] might have elicited a moderate level of physical stress for the participants that "boosted" positive and high-arousal negative word effects such that the sample size of 20 was enough to detect statistical effects. Examining the exact t-values in our study, however, did not hint towards a tendency of these main effects, suggesting that these missing findings were not a matter of sample size.

Hofmann and colleagues [6] were targeting very early ERP effects of affective word features around 100 ms after stimulus presentation. Therefore, participants were put under severe time pressure by forcing them to respond within one second (see [6] for a thorough discussion). Hofmann and colleagues [6] found no effects of emotional valence on the LPP available in emotional face or word stimuli [49]. Therefore, we suggest that the present, very similar experimental paradigm resulted in a de-emphasis of later, more evaluative stages of processing [5]. To test for this hypothesis, future studies should explore Zen effects on affective word processing with lower time pressure using an experimental task emphasizing late evaluative processes [50].

Rather than finding emotion-specific effects of Zen, we showed that a 90-minute meditation session leads to generally faster word recognition in the LDT. The RTs of the comparison subjects did not change after the comparison intervention. A number of neurocognitive mechanisms might be instrumental in explaining these results.

First, meditation practice supports emotion regulation [3,16,19,20]. We assume that due to regulated emotions meditators, in the present study, participants were less distracted by the emotional content of word stimuli and therefore able to provide generally faster responses in the LDT. The reverse effect may be present in depressed participants. Siegle and colleagues [36] found that in a LDT dysphoric subjects recognized negative and positive words significantly slower than neutral words. In this case, increased emotions may have distracted participants, slowing down word processing.

Second, meditation practice may lead to the acceleration of RTs, because of an augmentation in practitioners' focused attention. Several experimental studies support this view: Slagter and colleagues [15] found that a 3-month intensive meditation practice can reduce the attentional-blink deficit: When two target stimuli are presented in rapid succession, the second target stimulus is often not consciously recognized. In a study by Tang and colleagues [16], a group of novices practiced meditation for five days and a comparison group participated in a relaxation training for the same amount of time. The meditation group displayed significantly better results in the Attention Network Test

(ANT). Chan and colleagues [13] showed that meditation practice leads to reduced interference in the Stroop task, which suggests that meditation experience might increase the efficiency of the executive attentional network. Finally, in a study by Pagnoni and Cekic [14], comparison subjects showed a negative correlation of both gray matter volume and attentional performance with age, which was not evident for Zen practitioners. In the context of this literature, our globally facilitated RTs to word stimuli may well be explained by the improved attentional resources after Zen meditation.

Third, meditation practice may have accelerated RTs because of reduced mind-wandering. In a study by Brefczynski-Lewis and colleagues [51], expert meditators demonstrated decreased brain activation in regions of the default mode network, which is associated with discursive thoughts. Pagnoni and Cekic [52] also showed that meditation practice can reduce the neural activity associated with conceptual processing in default mode network regions. The authors suggest that meditation practice can support the control of automatic cascades of semantic associations and therefore facilitate the regulation of spontaneous mind-wandering. These processes might have helped Zen practitioners in the present study to stay focused on the presented word stimuli and thereby facilitated their responses.

Conclusions

The present work is the first to demonstrate that Zen meditation can lead to neutralized valence ratings of affective words. We assume that emotion regulation, elicited by the meditation intervention, is primarily responsible for this effect. We found no differential emotion effects during lexical decision in the Zen vs. comparison group. While participants in the valence rating task have no real time constraints for an explicit emotional evaluation of the stimuli, affective information can only implicitly act on lexical decision performance. Moreover, time pressure in this experiment may have fostered an early affective-semantic evaluation that is not affected by meditation. Even though meditation did not influence the emotion effects during lexical decision, participants demonstrated globally faster word recognition after meditation. We suggest that greater attentional resources after meditation can best explain this result.

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5 Study 2: Meditation affects word recognition of meditation novices

5.1 Citation and author contributions

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Author contributions:

Larissa Lusnig: Planned the study, conducted the experiments, planned and performed the analyses, wrote the paper.

Ralph Radach: Planned the study, wrote the paper.

Markus J. Hofmann: Planned the study, planned and performed the analyses, wrote the paper.

5.2 Published manuscript

Meditation affects word recognition of meditation novices

Larissa Lusnig, Ralph Radach, Markus J. Hofmann

Abstract

This work represents one of the first attempts to examine the effects of meditation on the processing of written single words. In the present longitudinal study, participants conducted a lexical decision task and rated the affective valence of nouns before and after a 7-week class in mindfulness meditation, loving-kindness meditation, or a control intervention. Both meditation groups rated the emotional valence of nouns more neutral after the interventions, suggesting a general down-regulation of emotions. In the loving-kindness group, positive words were rated more positively after the intervention, suggesting a specific intensification of positive feelings. After both meditation interventions, response times in the lexical decision task accelerated significantly, with the largest facilitation occurring in the loving-kindness group. We assume that meditation might have led to increased attention, better visual discrimination, a broadened attentional focus, and reduced mind-wandering, which in turn enabled accelerated word recognition. These results extend findings from a previous study with expert Zen meditators, in which we found that one session of advanced meditation can affect word recognition in a very similar way.

Keywords: meditation, emotional valence, arousal, emotion regulation, lexical decision, LDT

Introduction

Research on meditation has sparked substantial scientific interest in recent years. The effects of meditation practice on increased attention have generated particular interest in the research community (Jha et al., 2007; Pagnoni & Cekic, 2007; Slagter et al., 2007). Meditation practice is associated with improved efficiency in attentional processing (van den Hurk et al., 2010) and increased sustained attention (Chambers et al., 2008; MacLean et al., 2010). Experienced meditators show reduced interference in the Stroop task compared to control subjects (Chan & Woollacott, 2007) and can decelerate binocular rivalry switching (Carter et al., 2005). Further, meditation practice can lead to a reduced thought distraction and a strengthened present focus (Kok & Singer, 2017). Tang et al. (2007) found that already after a 5-day meditation training, participants achieved more improved performance on the attention network test compared to a control group.

Substantial scientific research has focused on the effects of meditation on emotion regulation. Meditation practice can reduce negative affect (Sears & Kraus, 2009), regulate symptoms of anxiety (Hofmann et al., 2010; Tang et al., 2007), stress (Goyal et al., 2014), and depression (Grecucci et al., 2015; Tang et al., 2007). At work, meditation can lead to reduced emotional exhaustion and increased job satisfaction (Hülsheger et al., 2013). In meditators, brain gray matter density is increased in the left hippocampus (Hölzel et al., 2011), which is associated with emotion regulation (Corcoran et al., 2005).

In recent years, a new field of meditation research has been explored. A study by Tarrasch et al. (2016) was one of the first to examine the effects of meditation on reading performance. They found that subjects with developmental dyslexia and ADHD demonstrated significantly fewer reading errors after a 2-month mindfulness course. Their error rate dropped by 19% compared to their original performance. In addition, they showed increased sustained attention. Another study found that intensive meditation practice can reduce mindless reading (Zanesco et al., 2016). Already after a 5-day workshop in mindfulness-based stress reduction, participants of a pilot study demonstrated a significant increase in reading speed (Rice et al., 2020). This promising field of research is still widely unexplored. Since texts often contain words with an affective content it is also important to examine the effects of meditation practice on emotional word processing. In particular, it is not clear if different meditation styles have dissociable effects on reading speed and how fast single words with different emotional valences are processed. Basic scientific research on this topic is needed. In the current literature, we find evidence that meditation can influence the processing of emotional images. Meditators demonstrate a reduced emotional reactivity to affective images. In a study by Desbordes et al. (2012) participants showed reduced amygdala activation while watching emotional images. A decreased amygdala activation suggests that the affective images had a decreased emotional impact (Davis & Whalen, 2001). Subjects with extensive meditation experience showed less interference from affective images (Ortner et al., 2007). Chau et al. (2018) found that older subjects rate affective pictures more neutral subsequent to a meditation intervention. While these studies show that meditation can affect emotional picture evaluation, the impact of meditation on affective word processing has not yet been well explored.

Interindividual differences and word recognition

The emotional connotation of experimental word stimuli is usually assessed by valence ratings (Citron, 2012; Jacobs et al., 2015; Kissler et al., 2007; Vo et al., 2009). Based on such ratings researchers can select word material, for example, for lexical decision tasks (LDT). During the LDT, participants are presented with letter strings, which either form a word or a meaningless stimulus. Subjects must choose under pressure of time if a word is displayed or not (Meyer & Schvaneveldt, 1971; Rubenstein et al., 1970). Word stimulus properties like arousal, frequency, imageability, valence, and many others have been shown to have an impact on word recognition (Brysbaert et al., 2011; Hofmann et al., 2007; Kuchinke et al., 2007; New et al., 2006).

Interindividual differences can influence single word recognition as well. Self-secure subjects demonstrated faster identification of words expressing positive interpersonal outcomes compared to participants that are more insecure. Insecure subjects recognized words faster that expressed negative interpersonal outcomes (Baldwin et al., 1993). In a valence identification task, dysphoric subjects needed significantly more time to recognize the valence of positive words than they needed to identify the valence expressed by negative words when contrasted with non-dysphoric participants. In an LDT, non-dysphoric participants demonstrated faster recognition of negative in comparison to neutral words. Dysphoric subjects, on the other hand, responded slower to negative than to neutral words (Siegle et al., 2002). Mueller and Kuchinke (2016) linked goal-directed behavior to slower processing of fear words. Further, they tied the spontaneous eye-blink rate, which indexes dopaminergic levels, to a processing advantage for happy words. If and to what extent the processing of words may also be influenced by meditation, is so far not well understood.

Our previous study

In a prior study, we examined if meditation has an impact on the responses to affective and neutral words in an LDT and on the valence ratings of these words (Lusnig et al., 2020). Experienced Zen meditators rated the valence of low-arousal positive and low- and high-arousal negative words more neutral, subsequent to a 90-min meditation session. In an age- and gender-matched comparison group, valence ratings did not change significantly after the comparison intervention. In the LDT, the Zen group showed an accelerated word recognition subsequent to the meditation intervention. The comparison group did not show a significant change in response times (RTs) after the comparison intervention. Because the effect of learning to meditate could not be investigated in these expert meditators, a longitudinal study, examining participants before and after they learned to meditate, is needed.

The present study

In the present work, we adapted the design of our previous study (Lusnig et al., 2020) for a longitudinal study. Two experimental groups and a control group (CG) participated in a meditation or control class. Before and after these interventions, all groups performed an LDT and a valence-rating task, along with a brief mood-states assessment. At baseline, subjects completed assessments on concentration capacity, intelligence, and personality traits. One experimental group participated in a 7-week class in mindfulness meditation. Mindfulness meditation is a widely used meditation style, which is similar to Zen meditation. During mindfulness meditation, the practitioner develops an effortless and non-judgmental awareness of all present-moment experiences (Kabat-Zinn, 1990). The second experimental group practiced loving-kindness meditation (LKM) for 7 weeks. LKM contains the practice of empathy, first the feeling of loving kindness is directed towards oneself and then towards others (Lutz et al., 2007). The control group participated for 7 weeks in a study group. As in the previous study, we used the low-arousal positive, low- and high-arousal negative and neutral word stimuli of Hofmann et al. (2009) and Lusnig et al. (2020). The quantity of these word stimuli was doubled for the current study.

In our prior work (Lusnig et al., 2020), the Zen group responded in an LDT globally faster to the same stimulus words after the meditation intervention than before the meditation. For the LDT of the present study, we expected both meditation groups to process word stimuli faster after the meditation classes than at baseline. Particularly mindfulness meditation has been associated with increased attention (Valentine & Sweet, 1999); therefore, we anticipated the greatest change in RTs in the mindfulness group (MG). We predicted that RTs in the control group would not differ significantly when compared before and after the control intervention. In the initial study by Hofmann et al. (2009), subjects responded slower to low-arousal negative words than to neutral words. In our previous meditation work, we replicated this result in the Zen- and the control group. Consequently, for the present study, the expectation was that all three groups would process low-arousal negative words slower than neutral words.

In Lusnig et al.'s (2020) valence-rating task, the Zen group rated positive, low- and high-arousal negative words more neutral after a single 90-min meditation session. The comparison group did not demonstrate significantly different valence ratings before and after the comparison intervention. Based on these results, we expected that both meditation groups would rate emotion words more neutral after the meditation classes. Especially LKM is associated with an increased experience of positive emotions (Zeng et al., 2015); therefore, we anticipated more positive valence ratings in the loving-kindness group (LKG) than in the MG. We also predicted that the control group would not rate the valence of emotion words significantly different after the control intervention. Participants performed assessments on personality traits, concentration capacity, and intelligence to control for interindividual differences between the three groups. We did expect, however, that mood states would change after the meditation interventions in the LKG and the MG, but not in the CG.

Methods and materials

Participants

Thirty-nine German native speakers participated in the present study. Thirteen of them took part in the LKG (12 female, 19–39 years of age, mean age = 22.2), thirteen in the MG (11 female, 19–44 years of age, mean age = 24.5), and thirteen in the CG (12 female, 19–42 years of age, mean age = 21.8). The formula of Westfall et al. (2014) was used to calculate an appropriate sample size. Variance partitioning coefficients were estimated based on the values of our previous study (Lusnig et al., 2020). To obtain a medium effect size of d = 0.5 and a power of 0.8 while using 400 word-stimuli per participant, a sample size of 11.8 participants per group is required. As mentioned above, we worked with a sample size of 13 participants per group. Thirty-eight participants were right-handed one was left-handed. All subjects were students of the University of Wuppertal; they were recruited via online advertisements. Subjects were randomly assigned to the three groups. None of the participants reported prior experience with meditation or yoga. None of them had a history of psychiatric disorders or any reading and writing difficulties. All participants received course credits for participation.

Covariates

Participants completed, at first, the “Aktuelle Stimmungsskala” (ASTS) to examine possible changes in mood states provoked by the interventions in every group. The ASTS measures subjects’ current mood states; the scales are “positive mood”, “sorrow”, “desperateness”, “fatigue” and “anger”. The internal consistency has Cronbach’s α values between $\alpha = 0.83$ and 0.94. Factor analysis provided one, two and four factor-based approaches. The author provides evidence for convergent and differential validity (Dalbert, 1992a, 1992b). Participants conducted this test at baseline and after the interventions. Possible significant group differences in personality traits, sustained attention, and intelligence were examined by covariate tests, which subjects conducted at baseline. Subjects performed the d2-Revision test (d2-R), an assessment of sustained attention and the ability to focus on task. In the d2-R, subjects have to find the letter “d” with two marks while not getting distracted by similar-looking stimuli. Cronbach’s alpha values are for the scales “number of processed target objects” and for “concentration capacity” are between $\alpha = 0.89$ and 0.95, for “percentage of errors” between $\alpha = 0.80$ and 0.91, depending on the age group. Authors provide empirical evidence for criterion and construct validity (Brickenkamp et al., 2010). This was followed by the Multiple-Choice Vocabulary Intelligence Test (MWT-B). Here, participants have to point out a correct German word among four similar nonwords in a multiple-choice procedure. It contains 37 items, which are sorted by level of difficulty. For the MWT-B retest reliability is reported with a correlation of $r = 0.95$ after 6 months and $r = 0.87$ after 14 months. The author provides empirical evidence for criterion validity (Lehrl, 2005). At last, subjects performed the Big Five personality test (B5T), which measures personality traits as specified in the Big Five model of personality. The B5T had in the original version five scales “neuroticism” (Cronbach’s alpha, $\alpha = 0.90$), “conscientiousness” ($\alpha = 0.77$), “extraversion” ($\alpha = 0.87$), “agreeableness” ($\alpha = 0.76$) and “openness to experience” ($\alpha = 0.76$). For the revised version, which was used in the present study, three basic requirements “need for power and influence” ($\alpha = 0.78$), “need for safety and peace” (α = 0.84), and “need for achievement and performance” (α = 0.82) were added. The test demonstrates factorial validity (Satow, 2011).

Stimuli

The stimulus set included 400 words (German nouns) and 400 altered words (nonwords). Half of the item set was taken from Hofmann et al. (2009), while the other half was generated using the same construction rules. All stimulus words were part of the revised Berlin Affective Word List (BAWL-R; Vo et al., 2009). The stimulus set contained four stimulus conditions: low-arousal negative, high-arousal negative, (low-arousal) positive, and neutral words. The stimulus condition “High-arousal positive words” could not be generated because the BAWL-R did not provide enough high-arousal positive nouns (cf. Hofmann et al., 2009; Lusnig et al., 2020; see Fig. 1 in Vo et al., 2009). Each of the four stimulus conditions of the whole item set contained 100 words. Low-arousal negative, positive and neutral words were matched for arousal. High-arousal negative words were matched for valence to low-arousal negative words, but their arousal values were maximized. Nouns were matched for the following psycholinguistic variables, which can influence LDTs: arousal, word frequency, emotional valence, number of orthographic neighbors, number of letters, imageability, mean bigram frequency (type), and mean bigram frequency (token) (see Table 1, and Table 1 in Hofmann et al., 2009). The selected nouns were modified to create nonwords. For this purpose, a vowel of a word stimulus was replaced by a consonant or another vowel. Stimuli were subdivided in Subset A and Subset B, each consisting of 200 words. To test whether the materials were matched for these variables, we conducted 2 × 4 ANOVAs (subset × emotion condition; all Fs < 1).

Table 1. Mean values and standard errors of the manipulation and control variables for high-arousal negative, low-arousal negative, positive, and neutral words

Control and manipulation variables	High-arousal negative words		Low-arousal negative words		Neutral words		Positive words	
	M	SE	*M*	SE	*M*	SE	*M*	SE
Emotional valence	− 1.31	0.05	− 1.30	0.04	0.06	0.04	1.17	0.07
Arousal	3.90	0.03	2.83	0.04	2.82	0.03	2.82	0.03
Imageability	4.50	0.17	4.11	0.20	4.24	0.16	4.26	0.16
Number of letters	6.42	0.17	6.06	0.21	6.16	0.18	6.18	0.19
Word frequency	12.94	0.31	13.20	0.38	12.62	0.29	12.56	0.27
Number of orthographic neighbors	0.98	0.24	1.50	0.30	1.20	0.24	1.18	0.27
Mean bigram frequency (type)	3113.55	284.41	3408.68	245.04	3525.47	272.50	3223.81	277.65
Mean bigram frequency (token)	167,061.37	19,957.41	189,351.71	21,027.04	190,835.14	19,536.51	178,481.74	20,794.76

Procedure

Pre-test

Subjects first completed the ASTS, then the d2-R, the MWT-B, and the B5T. Subsequently, subjects took part in the main experiment. Stimuli were presented on a 21-inch TFT display running at 70 Hz, with the distance between eyes and monitor held constant at approximately 65 cm.

Participants with even participant numbers were presented with Subset A of the stimuli set. They were asked to press key “2”, using the left index finger when identifying a nonword, and to press key “8”, using the right index finger when they recognized the stimulus as a word. After participants had processed the first half of Subset A, they were presented with the second half of subset A. To balance for RT differences due to hand dominance, subjects now pressed key “2”, using the left index finger when identifying a word, and pressed key “8”, using the right index finger when they identified a nonword. This way we also excluded the risk that possible effects were caused by the composition of one of the subsets, for instance by mood induction due to many words of the same emotion category (Niedenthal & Setterlund, 1994). Participants with uneven participant numbers were presented first with the first half of Stimulus Subset B, pressing the left index finger for a word. In the second half of Subset B, hand assignment was reversed. In any case, responses were to be executed as quickly and accurately as possible.

Before the LDT, participants were made familiar with the test by responding to five practice stimuli. The word stimuli appeared in black uppercase letters on a light gray background, in 20 pt Times New Roman font using presentation-software PsychoPy, version 1.82.01 (Peirce, 2007). Stimuli were pseudorandomized. At most three words or nonwords were presented consecutively. During each trial, for 700 ms, a fixation cross (+) was displayed, followed by a word or nonword for 1000 ms. A white screen was shown for 500 ms and then for 1500 ms a mask (#####) (see Fig. 1 in Lusnig et al., 2020). After a 5-min break, subjects rated the valence of the words, which they had seen before in the LDT. One word at a time was presented on the screen. Below every word, a seven-point grading scale from − 3 to 3 was displayed (0 = neutral, − 3 = very negative, 3 = very positive). Subjects gave their responses by clicking the respective number with the cursor. After pressing the space bar, the next word appeared on the screen. The duration of the LDT was about 20 min followed by a 5-min break, the valence rating task lasted for approximately 12 min. The whole experiment, including also covariate tests and instructions, lasted approximately 75 min.

Post-test

Subjects took part in the post-test about 1 week after having finished one of the meditation classes or the study group. Participants first finished the ASTS, other covariate tests were not conducted during the post-test. The instructions and procedures for the LDT were the same as the ones given in the pre-test. Participants with even numbers were presented with stimulus Subset B, subjects with uneven participant numbers completed Subset A. Participants took a 5-min break. Then, they rated the valence of the words they had seen during the post-LDT.

Meditation or comparison interventions

The week after the pre-test, all subjects took part in a 1.5-h intervention in the morning on the same day of the week. The training took place in 8 consecutive weeks. In the fourth week, training was suspended due to a national holiday. A local experienced meditation-trainer led both meditation groups.

Mindfulness meditation intervention

Participants of the MG learned at first which sitting postures are adequate for meditation, how to relax their body, and how to breathe calmly and naturally. Then, they practiced observing their thoughts, emotions, and physical feelings and tried to let them go instead of being caught up in them.

Loving-kindness meditation intervention

First, subjects of the LKG practiced suitable sitting postures for meditation, how to exercise a natural and calm breath, and technics to relax their body. They learned how to be aware of their thoughts, emotions, and feelings and trained to develop equanimity and self-empathy regarding these states. Gradually subjects broadened their empathy to their feelings and emotions and situations of others, also using visual imagery.

Control intervention

The study group aimed to involve subjects of the CG in a silent active control intervention very close to their usual activities. All participants were college students; therefore, a study group was selected as an adequate intervention. Participants were instructed to study silently for a class they were currently attending. An undergraduate assistant supervised the study group.

Data analysis

For the LDT, RTs of the correctly given answers were analyzed using linear mixed-effects models (LMEs). 14.95% of all responses were incorrect, they were excluded from the data analysis. The models were calculated with the statistical software environment R, (version 3.4.2, http://cran.r-project.org). Specifically, we used the lme4 library with the lmer function (version 1.1–14, Bates et al., 2015). The lmer function fits an LME to the data. An LME data analysis considers participant and item variance concurrently in a non-hierarchical approach. Averaging at first level treats the error variance of items as fixed effects. Separate random intercepts for subjects and items result in treating subject and item variance more sensitively. “Subjects” and “items” were fitted as random effects. As fixed effects, we fitted “groups” (LKG/MG/CG), “time” (before/after intervention) and “emotional valence” (positive words/low-arousal negative/high-arousal negative). Fixed effects were represented with the use of effects coding. Low-arousal negative, high-arousal negative, and positive words were confronted with neutral words. We calculated a time slope for the random effect “item” because the time-series effect might be different for different items (Baayen et al., 2008). For every group, separate LMEs were calculated to examine the origin of significant interactions. The dependent variable “response time” was log-transformed to satisfy the assumption of normality of the residuals, which were verified by qqplots. Estimates of the regression coefficients, their standard errors, and t values are reported for the LMEs. P values are reported on the basis of the Satterthwaite approximation, which is implemented in the lmerTest package, (Version 2.0-36, Kuznetsova et al., 2017).

Regarding the valence rating experiment, we examined responses given on a seven-point grading scale ranging from − 3 to 3. An LME was used again to analyze the experimental data. The procedure of the data analysis was the same as for the response time experiment. Data points, which were not in a range between – 3 and 3 standard deviations of the residual error, were discarded from the calculations (approximately 1% of the data). To analyze the results of the ASTS we conducted a 3 × 2 × 5 ANOVA with the factors “group”, “time” and “mood conditions”.

Results

Covariates

To control for a possible change in mood induced by the interventions, subjects completed the ASTS at baseline and after interventions. Mood did not change significantly over time points in any of the groups. Mood conditions (positive mood, sorrow, desperateness, fatigue, and anger) were rated significantly different (see Table 2). This effect demonstrates, for example, the difference between positive mood and sorrow; for the discussed effects of the present study, however, it does not have relevance. In addition, subjects were tested at baseline for group differences in personality traits, intelligence, and concentration capacity to control for influences of these factors on the RT results. In these comparisons, no significant group differences were found. All statistical values for group differences, mean values, and standard deviations of the baseline covariate tests are reported in Table 3.

Table 2. Statistical group differences and mean squared errors (MSE) of ASTS (tested at baseline and after intervention)

	Statistical group differences
Time	$F(1, 36) = 2.31$, $p = 0.14$, MSE = 4.13
Time: Group	$F(2, 36) = 2.39$, $p = 0.11$
Mood conditions	$F(1, 36) = 496.85$, $p = 0.00$, MSE = 54.32
Mood conditions: Group	$F(2, 36) = 1.04$, $p = 0.39$
Time: Mood conditions	$F(2, 36) = 0.29$, $p = 0.78$, MSE = 26.47
Time: Mood conditions: Group	$F(2, 36) = 0.61$, $p = 0.66$

Time (before/after intervention), Group (LKG/MG/CG), mood conditions (positive mood, sorrow, desperateness, fatigue, and anger)

Table 3. Baseline covariate tests: statistical group differences, mean squared errors (MSE), mean values, and standard deviations

Covariate test	**Statistical group differences**	**LKG**		**MG**		**CG**	
		M	**SD**	***M***	**SD**	***M***	**SD**
Big Five personality test							
Neuroticism	$F(2, 36) = 2.37, p = 0.11$, MSE = 2.01	4.85	1.86	4.77	1.34	3.77	1.01
Extraversion	$F(2, 36) = 0.46, p = 0.63$, MSE = 3.16	5.69	1.60	5.77	2.39	6.31	1.11
Conscientiousness	$F(2, 36) = 1.30, p = 0.29$, MSE = 4.39	4.23	1.92	5.54	2.15	4.69	2.21
Agreeableness	$F(2, 36) = 1.18, p = 0.32$, MSE = 2.41	5.15	1.68	5.92	1.71	6.00	1.23
Need for safety and peace	$F(2, 36) = 2.96, p = 0.06$, MSE = 1.74	4.62	1.19	5.46	1.56	4.23	1.16
Need for power and influence	$F(2, 36) = 0.71, p = 0.50$, MSE = 2.86	4.54	1.81	4.31	1.55	5.08	1.71
Openness	$F(2, 36) = 2.83, p = 0.07$, MSE = 2.07	5.77	1.59	5.38	1.04	4.46	1.61
Need for achievement and performance	$F(2, 36) = 0.01, p = 0.99$, MSE = 3.03	5.00	1.87	5.08	1.89	5.00	1.41
d2-Revision, test concentration capacity							
Number of processed target objects	$F(2, 36) = 2.18, p = 0.13$, MSE = 465.78	163.77	22.06	179.00	21.72	179.15	20.96
Concentration capacity	$F(2, 36) = 1.91, p = 0.16$, MSE = 666.45	143.38	28.31	161.38	28.47	159.53	19.68
Percentage of errors	$F(2, 36) = 1.89, p = 0.17$, MSE = 22.52	11.37	4.72	8.24	4.35	11.37	5.14
Intelligence test (MWT-B)	$F(2, 36) = 2.05, p = 0.14$, MSE = 6.78	22.23	2.52	23.37	2.36	21.31	2.89

Lexical decision and valence rating data

Figure 1 shows that after the loving-kindness- and the mindfulness-meditation sessions affective valence ratings were more neutral, except for valence ratings to positive words in the LKG, which became more positive. Figure 2 shows that RTs in the LDT were shorter after both meditation interventions, but not after the control intervention. The LME analysis revealed for the valence rating as well as for lexical decision data significant interactions of “group” and “time” (see Table 4 for entire analysis). The valence rating data showed for “time” as well as for “group” significant two-way interactions with “positive”, “high-arousal negative”, and “low-arousal negative” words. Further, we found significant main effects for “high-arousal negative”, “low-arousal negative” and “positive” words. The analysis of the lexical decision data revealed for "low-arousal negative" words a significant main effect. Separate LMEs were subsequently calculated for all three groups to resolve the significant interactions of “time” and “group” (cf. Table 5). For the valence rating and lexical decision data, we found significant main effects for “time” in the LKG and the MG, but not in the CG.

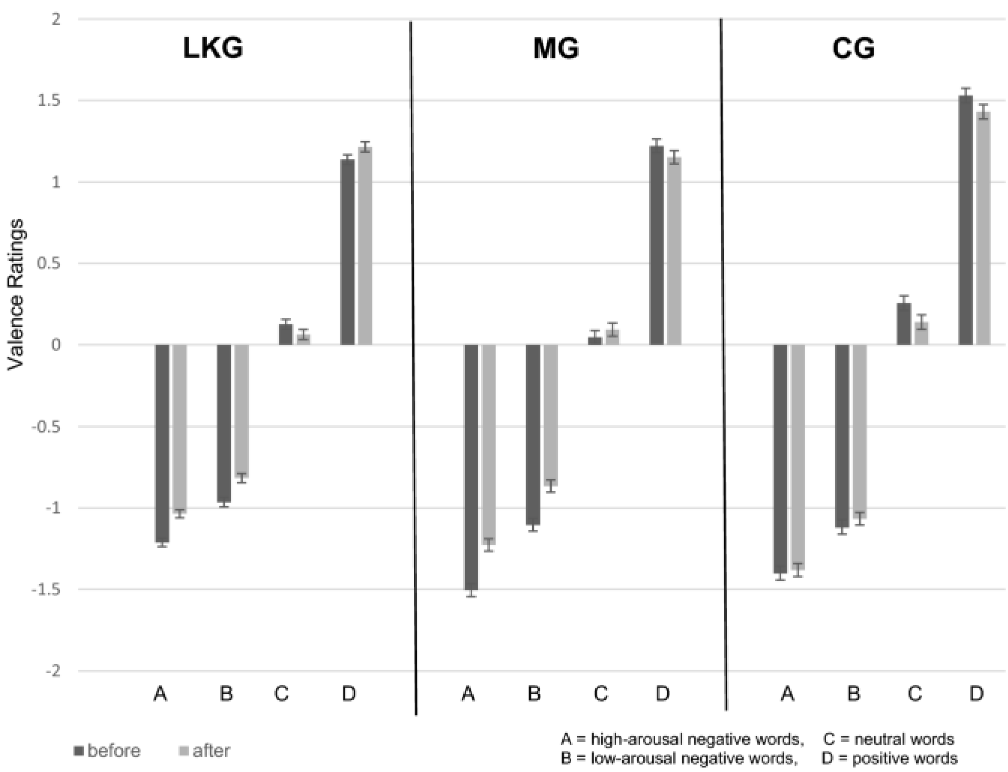

Fig1. Results of the valence rating experiment. Error bars indicate standard errors

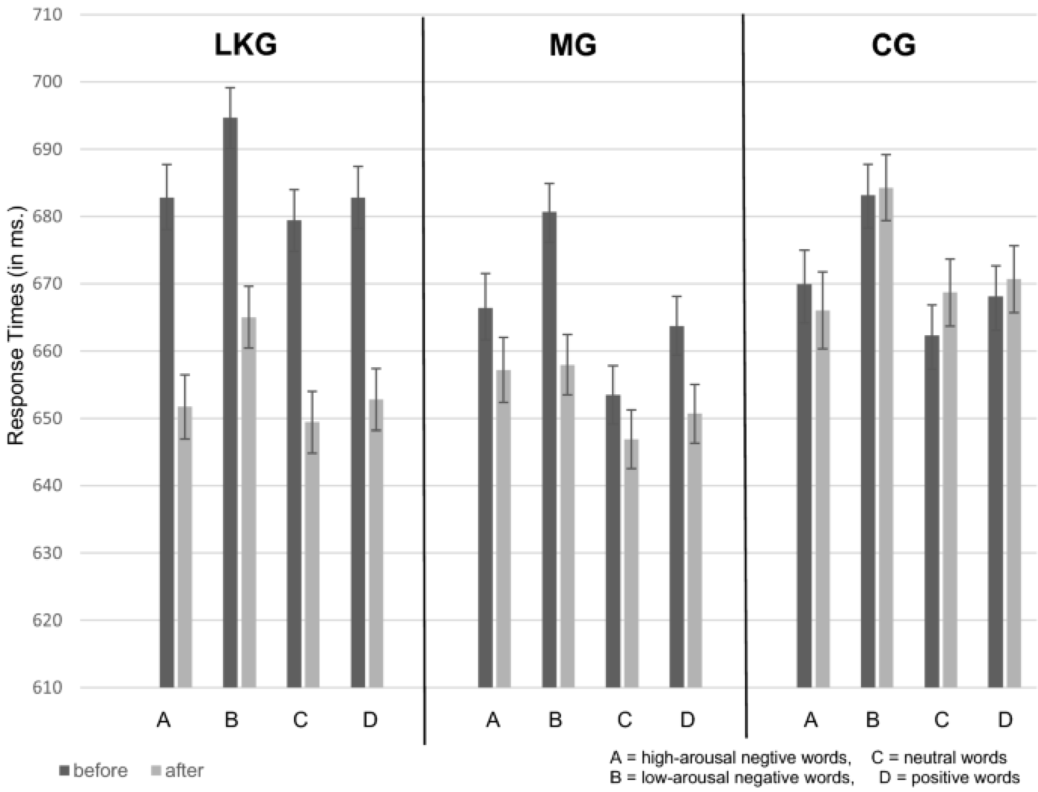

Fig 2. Results of the lexical decision experiment. Error bars indicate standard errors

Table 4. Valence rating and LDT Experiments: estimates of regression coefficients, their standard errors, t values, p values, and Cohen's d effect sizes of the overall *analyses*

	Valence ratings					Lexical decision task				
	B	**SE**	***t***	***p***	***d***	***B***	**SE**	***t***	***p***	***d***
Time	0.013	0.024	0.54	0.592	0.01	− 0.002	0.004	− 0.55	0.586	− 0.02
Group	− 0.009	0.032	− 0.28	0.783	− 0.15	0.006	0.016	0.41	0.688	0.13
High-arousal negative	− 1.273	0.052	− 24.57	0.001***	− 1.91	0.001	0.008	0.01	0.997	0.01
Low-arousal negative	− 0.933	0.052	− 18.01	0.001***	− 1.40	0.026	0.008	3.28	0.001**	0.27
Positive	1.739	0.052	33.59	0.001***	2.64	− 0.006	0.008	− 0.82	0.412	− 0.07
Time:group	0.039	0.015	2.70	0.007**	0.04	− 0.022	0.003	− 8.21	0.001***	− 0.15
Time:high-arousal negative	0.084	0.042	2.00	0.045*	0.08	− 0.006	0.006	− 0.96	0.335	− 0.04
Group:high-arousal negative	0.128	0.018	7.08	0.001***	0.09	− 0.001	0.003	− 0.35	0.730	− 0.01
Time:low-arousal negative	0.106	0.042	2.53	0.011*	0.09	− 0.001	0.006	− 0.14	0.890	− 0.01
Group:low-arousal negative	0.102	0.018	5.66	0.001***	0.07	− 0.003	0.003	− 0.85	0.394	− 0.02
Time:positive	− 0.106	0.042	− 2.53	0.011*	− 0.11	− 0.002	0.006	− 0.31	0.758	− 0.01
Group:positive	− 0.180	0.018	− 9.95	0.001***	− 0.13	0.001	0.003	0.30	0.768	0.01
Time:Group:high-arousal negative	0.017	0.026	0.68	0.499	0.01	0.004	0.005	0.89	0.373	0.02
Time:Group:low-arousal negative	− 0.021	0.026	− 0.82	0.412	− 0.01	0.001	0.005	0.08	0.933	0.01
Time:Group:positive	0.037	0.026	1.44	0.149	0.02	− 0.001	0.005	− 0.28	0.777	− 0.01

“***” $p < 0.001$, “**” $p < 0.01$, “*” $p < 0.05$

Table 5. Valence rating and LDT experiments: estimates of regression coefficients, their standard errors, t values, p values, and Cohen's d effect sizes for the LKG, MG, and CG

	Valence ratings					Lexical decision task				
	B	SE	*t*	*p*	*d*	*B*	SE	*t*	*p*	*d*
LKG										
Time	0.078	0.026	3.08	0.002**	0.31	− 0.048	0.004	− 12.41	0.001***	− 0.41
High-arousal negative	− 0.980	0.051	− 19.22	0.001***	− 1.92	− 0.003	0.008	− 0.32	0.747	− 0.03
Low-arousal negative	− 0.728	0.051	− 14.27	0.001***	− 1.43	0.016	0.008	1.98	0.048*	0.20
Positive	1.361	0.051	26.69	0.001***	2.67	− 0.004	0.008	− 0.55	0.585	− 0.06
Time:high-arousal negative	0.094	0.044	2.12	0.035*	0.21	− 0.001	0.007	− 0.21	0.833	− 0.01
Time:low-arousal negative	0.053	0.044	1.20	0.231	0.12	0.006	0.007	0.81	0.417	0.03
Time:positive	− 0.011	0.044	− 0.25	0.801	− 0.03	− 0.004	0.007	− 0.57	0.569	− 0.02
MG										
Time	0.125	0.025	4.91	0.001***	0.19	− 0.022	0.004	− 5.96	0.001***	− 0.62
High-arousal negative	− 1.172	0.054	− 21.78	0.001***	− 2.14	0.001	0.008	0.01	0.993	0.01
Low-arousal negative	− 0.768	0.054	− 14.28	0.001***	− 1.41	0.027	0.008	3.49	0.001***	0.35
Positive	1.554	0.054	28.90	0.001***	2.85	− 0.005	0.008	− 0.70	0.484	− 0.07
Time:high-arousal negative	0.157	0.044	3.56	0.004***	0.14	− 0.005	0.006	− 0.78	0.435	0.08
Time:low-arousal negative	0.115	0.044	2.60	0.009**	0.10	− 0.013	0.006	− 1.94	0.053	− 0.19
Time:positive	− 0.194	0.044	− 4.40	0.001***	− 0.17	− 0.002	0.006	− 0.27	0.785	− 0.03
CG										
Time	− 0.026	0.027	− 0.95	0.342	− 0.03	− 0.001	0.004	− 0.33	0.739	− 0.03
High-arousal negative	− 1.215	0.056	− 21.65	0.001***	− 2.14	− 0.003	0.008	− 0.33	0.745	− 0.03
Low-arousal negative	− 0.930	0.056	− 16.57	0.001***	− 1.64	0.023	0.008	2.78	0.006**	0.29
Positive	1.707	0.056	30.40	0.001***	3.00	− 0.004	0.008	− 0.53	0.594	− 0.06
Time:high-arousal negative	0.047	0.047	1.01	0.311	0.03	− 0.008	0.007	− 1.23	0.221	− 0.13
Time:low-arousal negative	0.077	0.047	1.66	0.098	0.05	0.006	0.007	0.90	0.368	0.09
Time:positive	− 0.050	0.047	− 1.06	0.287	− 0.03	− 0.003	0.007	− 0.52	0.603	− 0.06

"***" $p < 0.001$, "**" $p < 0.01$, "*" $p < 0.05$

Discussion

In the present study, we did not find any baseline differences in intelligence, concentration capacity, and personality traits between the three groups. Contrary to our expectations, mood changes could not be detected in the ASTS after any of the three interventions. Looking at word items, both meditation groups rated valence more neutral after the meditation interventions. Participants in the LKG, however, rated positive words more positively after the intervention. In the control group, valence ratings did not differ significantly after control intervention. Concerning the LDT, both meditation groups demonstrated faster word recognition after the interventions. This effect was most pronounced for participants in the LKG. The control group did not show significantly different RTs after the intervention. Hofmann et al. (2009) and our previous study found that low-arousal negative words were processed slower than neutral words. We replicated this effect in all three groups.

The valence rating experiment

Valence ratings differed significantly after the interventions in both meditation groups. After the control intervention, valence ratings did not change. Figure 1 demonstrates that the MG and the LKG rated words more neutral after the meditation classes. The LKG, however, rated positive words more positively after the meditation intervention. These results are in line with previous work on meditation and emotion regulation. Several studies showed that particularly mindfulness meditation can down-regulate negative emotions such as anxiety (Hofmann et al., 2010; Tang et al., 2007), stress (Goyal et al., 2014), and depression (Grecucci et al., 2015; Tang et al., 2007). The practice of LKM has also been associated with increased positive emotions (Fredrickson et al., 2008; Hutcherson et al., 2008; Zeng et al., 2015). However, contrary to our expectations, we did not find evidence for changes in mood states after any of the three interventions. The reason for this could be that the mood assessment we used (ASTS) might not be sensitive or specific enough to capture the emotion regulation produced by meditation. On the other hand, these results may indicate that meditation practice does not always lead to a reduced experience of emotions. The practitioners may still experience the emotions the way they did before but do not judge them and do not get carried away by them. The fact that we did not find changes in mood states, however, ensures that the neutralized valence ratings occurred due to the meditation interventions and were not influenced by a momentary mood change.

In our previous study (Lusnig et al., 2020), adept Zen meditators assigned to words significantly more neutral valence ratings after a 90-min Zen meditation. In the previous comparison group, valence ratings did not change after the comparison intervention. These results are in line with our findings for the MG in the present study. The similarity of these results was to be expected because Zen meditation and mindfulness meditation are comparable styles of meditation. Both meditation styles belong to the category of open monitoring meditation (OMM) (Lutz et al. 2008), during which the meditator monitors, in a non-judgmental way, everything that occurs in his moment-to-moment experience, such as sounds, thoughts that pass the mind, smells, or feelings. According to Lutz et al. (2007), LKM can be seen as a special case of OMM because it contains the "cultivation of objectless awareness" and "non-referential compassion". However, it contains also phases of focused attention meditation (FAM), during which the meditator keeps the attention all the time on one object. In the case of LKM, this object is the feeling of loving-kindness, which is directed towards oneself or other single persons (Lutz et al., 2007; Vago & Silbersweig, 2012). In the present work, the LKG rated positive words more positively after meditation. In the MG and the Zen group of the previous study, we did not find such an effect. LKM differs from mindfulness- and Zen meditation because it contains the practice of empathy and positive feelings towards others. This difference in meditation practice may have led to the more positive valence ratings in the LKG. A study by Hunsinger et al. (2013) found results similar to our study. In their work, loving-kindness novices associated significantly more positivity with neutral stimuli after a meditation intervention compared to control participants.

The lexical decision experiment

Half of the stimulus set used in the present study was identical to the one used by Hofmann et al. (2009). They found, among other results, low-arousal negative words being processed slower than neutral words. In the present study, we replicated this effect in all three groups. In our previous work (Lusnig et al., 2020), we obtained this result in the Zen and the control group. In the current literature, it is discussed if positive or negative visual stimuli are processed more rapidly. For example, Öhman et al. (2001) found that threatening faces are processed faster than friendly faces. On the other hand, a study by Becker et al. (2012) demonstrated that dynamic happy facial expressions are detected faster than dynamic angry facial expressions. Hofmann et al. (2009) found that the arousal level affects the processing speed of emotional single words. In their study, high-arousal negative words and positive words are processed faster than low-arousal negative words. In the present study, we found the same descriptive result pattern in all three groups (see Fig. 2). The MG, however, demonstrates after the meditation intervention no difference in processing speed for high-arousal negative, low-arousal negative, and positive words (see Fig. 2). This might be because the profound practice of equanimity in mindfulness meditation minimizes the difference in arousal level for negative words.

In both meditation groups of the present study, but not the control group, RTs changed significantly after the interventions. As illustrated in Fig. 2, RTs to emotional words were faster after both meditation interventions. These results are also in accordance with those of our previous study, in which the Zen group demonstrated a significantly faster word recognition after a 90-min meditation session. Meditation is associated with increased attention (Carter et al., 2005; Chambers et al., 2008; MacLean et al., 2010; Chan & Woollacott, 2007; van den Hurk et al., 2010). Hence, it appears plausible to conclude that increased attentional resources in the meditation groups may have led to accelerated word recognition. As an alternative account, the shorter RTs could be associated with reduced mind-wandering as a result of meditation. Using functional MRI, Brefczynski-Lewis et al. (2007) found that expert meditators showed less brain activation in the default mode network. The default mode network is associated with discursive thoughts. Similarly, a study by Pagnoni et al. (2008) found in meditators decreased neural activity in default mode network regions. These authors propose that meditators may be able ‘to control the automatic cascade of semantic associations’ better than control subjects (Pagnoni & Cekic, 2007, p. 1). Therefore, spontaneous mind-wandering could be regulated more easily. In the present study, regulated mind-wandering may have helped the participants of the meditation groups to focus more closely on the current word stimulus, enabling faster responses.

Improved visual discrimination could be another process that may have contributed to faster RTs in the MG and the LKG. Expert meditators demonstrate visual attentional processing, which is more accurate and flexible in contrast to control subjects’ visual processing. For example, meditators notice changes in flickering scenes faster than controls (Hodgins & Adair, 2010). Brown et al. (1984) tested Buddhist meditators before and after a 3-month meditation retreat for visual sensitivity. After the meditation intervention, meditators noticed shorter single-light flashes and could differentiate better successive light-flashes than before the retreat. A control group did not show any such changes in visual sensitivity. In a study by MacLean et al. (2010), meditation novices improved after a 3-month meditation training visual discrimination, perceptual sensitivity, and increased vigilance during visual attention. This evidence points to the possibility that in the present study meditation training might have led to improved visual sensitivity and discrimination performance, which in turn allowed for faster responses in the LDT.

We expected that the MG would show the largest decrease in RTs after intervention because especially mindfulness meditation has been associated with increased attention (Semple, 2010; Valentine & Sweet, 1999). There was indeed a substantial response acceleration, but in our data, this effect was even more pronounced in the LKG. These results might be explained considering the association between meditation styles and narrow or broad attentional focus. Lippelt et al. (2014) argued that FAM, which contains mainly a strong concentration on a single object, leads to a narrow focus of attention. During OMM the meditator monitors all experiences non-judgmentally. This meditation style is, therefore, thought to lead to a broad attentional focus. Such a broadened attentional focus was shown to promote better performance on an attention task (Willems & Martens, 2016). In the present study, a broad attentional focus, induced by the mindfulness meditation, might have led to a more effective and therefore faster word processing. The practice of LKM contains open monitoring, the main goal of this meditation style is to broaden the feeling of loving-kindness starting from a person we like to everyone. This broadened attentional focus combined with the strong cultivation of loving-kindness might have helped the LKG to process the emotional words especially fast. Since positive affect is also associated with a broader attentional focus (Fredrickson & Branigan, 2005), the feeling of loving-kindness might have given an additional speed boost in the LKG. It would be very interesting for subsequent research to compare not just the influence of mindfulness meditation and LKM on word processing but also the effects of FAM. This way the effects of narrowed and broadened attentional focus could be compared.

Future directions and limitations

Concerning the sequence of experimental and covariate tests in the present study, it might have been better to give to the participants first the ASTS, then the LDT and the valence rating task, and at last the remaining covariate tests. This way the mood states, which were measured with the ASTS could not have been changed through tiring covariate tests. However, since in the present study the ASTS results were not influenced by the meditation intervention, the test plays a minor role in the interpretation of our study, and we do not see problems with the sequence of the tests.

For future studies on the influence of meditation and visual word processing it might also be beneficial to use assessments on emotion regulation and increased attention not just before the meditation intervention, as in the present study, but also after it. With such an experimental design it could be extensively examined which of these underlying mechanisms of meditation influences altered word processing in meditation practitioners the most. It would be especially informative to investigate further the role of emotional variability. We would suggest that subjects should conduct adequate emotion assessments at baseline, two times during the intervention and after it.

The present study and our previous study (Lusnig et al., 2020) focused on the question if meditation practice can influence visual single word processing. Since we found that meditation practice can accelerate the responses to single words and neutralize the valence ratings of emotion words, it would be interesting to examine in the future if meditation might have similar effects on the processing of entire written texts. If the effects of meditation practice on written texts are similar to those on single words, it can be assumed that meditation can accelerate the reading speed of practitioners, as suggested also by a pilot study by Rice et al. (2020). It seems also important to examine clearly how meditation styles lead to a narrow or broad attentional focus and how such a focus affects word and text processing. Lippelt et al. (2014) proposed that FAM leads to a narrow attentional focus and that OMM induces a broadened attentional focus. It seems important to examine clearly in experimental studies how these attentional foci affect word and text processing. The further examination of narrow and broad attentional foci, triggered by meditation, could also have important implications for the treatment of anxiety disorders. Richards et al. (2014) claimed that anxious persons, who show hypervigilance, demonstrate a broadened attentional focus that scans for potential threats in the environment. The practice of FAM could be helpful for these individuals to deliberately narrow their focus on an object like the breath and calm themselves down. On the other hand, Richards et al. (2014) argued that people with anxiety disorders show, in confrontation with a specific threatening stimulus, a narrow attentional focus. OMM could help persons, in such situations, to deliberately broaden their attention and thereby allow them to detach their attention from the threatening stimulus.

Conclusions

In a previous study Lusnig et al. (2020), we found that advanced Zen meditation can neutralize valence ratings of emotional words and accelerated RTs to these words. In the present study, we were able to obtain similar results with a longitudinal study design. Subjects, which participated in a 7-week loving-kindness- or mindfulness course, demonstrated significantly more neutral valence ratings after the interventions. Positive words were rated more positively after the LKM course. These results suggest that different meditation styles can contribute to the down- and up-regulation of emotions. However, contrary to our expectations, mood states did not appear to change after meditation interventions. In both meditation groups, RTs were faster after the interventions than before, with the largest changes occurring in the LKG. Improved increased attention, visual discrimination, and reduced mind-wandering, caused by meditation, may have enabled accelerated word recognition. The results of the present study could help to understand better the influence of meditation in text processing of affectively loaded content.

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Ethics declarations

Conflict of interest/competing interests

The authors declare that they have no conflict of interest.

Ethics approval

The present study was carried out following the ethical standards provided by the Declaration of Helsinki and the German Society for Psychology (DGPs). The Ethics Committee of the University of Wuppertal approved the study.

Consent to participate

All subjects gave their written informed consent.

Consent for publication

We did not use participant identifying information.

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6 Study 3: Mindful Text Comprehension: Meditation Training Improves Reading Comprehension of Meditation Novices

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Author contributions:

Larissa Lusnig: conceptualization, writing - original draft, data curation, formal analysis, methodology, project administration. All authors read and approved the final version of the manuscript for submission.

Markus J. Hofmann: conceptualization, writing - review and editing, formal analysis, supervision, methodology, project administration.

Ralph Radach: conceptualization, writing - review and editing, supervision, methodology.

6.2 Published manuscript

Mindful Text Comprehension: Meditation Training Improves Reading Comprehension of Meditation Novices

Larissa Lusnig, Markus J. Hofmann, Ralph Radach

Abstract

Objectives. Research on the effects of meditation practice on reading performance is a new and promising field of research. However, the evidence on whether meditation improves reading comprehension and/or speed in continuous reading is inconclusive. The present work addresses this question.

Method. For the present longitudinal study, undergraduate students ($n = 52$) participated in a 6-week mindfulness meditation course or an active control condition. We assessed reading comprehension and speed before and after the intervention/control condition, as well as emotion regulation, sustained attention, and personality traits.

Results. Reading comprehension improved significantly after the meditation intervention ($B = 2.15$, $t = 3.47$, $p = 0.002$, $d = 0.69$), but reading speed did not change, contrary to our expectations. The control group showed no significant changes in either text comprehension or reading speed. Further, we found that meditation led to better attention capacity. Improved attention was positively associated with improved reading comprehension in the meditation group, though attention capacity did not mediate the effect on text comprehension. While we found that meditation can increase the acceptance of one’s own emotions and decrease emotional overload, these covariates did not affect comprehension performance.

Conclusions. The present work shows that mindfulness meditation improves attention capacity and text comprehension. However, mindfulness meditation does not affect reading speed. Finally, we confirmed that meditation can help in emotion regulation.

Keywords: meditation, reading comprehension, attention, text comprehension, reading speed, mindfulness

Reading comprehension is an important field of research, given that reading for meaning is a key basis for successful participation in our society. Successful reading can be broken down into two main components: Word decoding and language comprehension (Gough & Tunmer, 1986; see Lonigan et al., 2018, for a recent review). In this context, successful word decoding is defined as efficient letter and word recognition, often assessed in relatively pure form by the ability to read out loud pseudowords (letter-strings without meaning). Language comprehension refers to "the ability to take lexical information … and derive sentence and discourse interpretations" (Hoover & Gough, 1990, p. 131). Over the last decades, research has made great progress in identifying important processes and mechanisms for successful reading comprehension (Perfetti et al., 2005). To list a few examples, vocabulary breadth and depth (Cain & Oakhill, 2014), reasoning skills (Cutting & Scarborough, 2006), and comprehension monitoring (Vorstius et al., 2013) have been shown to constitute essential components for the ability to understand texts adequately.

Despite significant societal investment and growing knowledge of effective teaching, there are still a substantial number of students, in different forms of schooling, who lack essential reading comprehension skills. For example, in Germany, about 20% of the 15-year-olds were not able to grasp the meaning of texts and to reflect on it (PISA, 2019). Therefore, unconventional approaches to solving the problem should also be considered. Meditation is a practice that is at least more than 2500 years old (Pandurangi et al., 2017) and intends to calm the mind, the emotions, and the thoughts. During meditation, practitioner learns to let a thought or an emotion come and go without judging it as good or bad. Emotion or thought is noted, but meditator is not getting further involved with it or lets mind get carried away because of that thought or emotion (Kabat-Zinn, 1990). A mind trained in this way is stable; it is not easily upset or distracted. This means that such a mind has the ideal prerequisites for mastering tasks where it is important to remain focused for a longer period. We follow the definition of mindfulness as full attention to the experiences of every present moment and the complete non-judgmental acceptance of all these experiences (Kabat-Zinn, 1990).

Research on the effects of meditation showed that meditation can improve attentional control (MacLean et al., 2010; see Lutz et al., 2008 for a review) and emotion regulation (Shapiro et al., 2008; Zhang et al., 2019), and reduce mind wandering (Mrazek et al., 2012; Taraban et al., 2017). All of these skills might be very helpful to stay on task during reading-related assessments like reading comprehension and speed. Following this rationale, in recent years, a new and promising field of research has started to explore the effects of meditation practice on performance in reading. Tarrasch et al. (2016) reported that dyslectic individuals and/or individuals with attention deficits demonstrated 19% fewer reading errors after a 2-month course in mindfulness meditation. At the same time, sustained attention also improved in these participants. Further, extensive meditation practice was found to reduce mindless reading and mind wandering during reading (Zanesco et al., 2016). A recent pilot study by Rice et al. (2020) suggested that as little as 5 days of mindfulness meditation practice can increase reading speed. Lusnig et al. (2020, 2022) found that various meditation technics can accelerate single word processing, while the capacity for emotion regulation was demonstrated by attenuated valence ratings for emotional words.

There is little research on whether meditation also has a positive effect on reading comprehension, and the results have been inconclusive. In a study by Clinton et al. (2018), 105 undergraduate students appeared to demonstrate better reading comprehension compared to a control group after practicing mindful breathing for as little as 15 min. However, comprehension was assessed using the Nelson-Denny test, which has been criticized for lack of validity, as many items can be solved correctly without reading the test passages (e.g., Coleman et al., 2010).

In a study by Mrazek et al. (2013), 48 undergraduate students participated either in a mindfulness meditation course or in a nutrition course. During the 2-week period, each course was held eight times for 45 min each. Before and after the intervention/control condition, participants completed assignments on reading comprehension and working memory. In addition, mind wandering during both tasks was assessed. After 2 weeks of meditation training, participants demonstrated both improved reading comprehension and working memory performance. Mind wandering during the assessments was reduced. The active control condition did not lead to any significant changes in reading comprehension, working memory performance, or mind wandering.

Some studies did not show effects of meditation on reading performance. Linden (1973) found that 26 third-grade students became more field-independent and less test anxious after 18 weeks of meditation practice. However, the meditation practice did not affect students' reading achievement, which included measures of reading comprehension. In a recent pilot study, Benney et al. (2021) examined whether mindfulness training, combined with reading fluency training, would help a fourth-grade student with learning disabilities to improve his reading fluency compared to the reading fluency training without a mindfulness intervention. Various analyses of these data did not find conclusive evidence on whether meditation leads to improved reading fluency.

The present study addressed these conflicting findings and aimed to answer the question of whether mindfulness meditation can affect reading comprehension. In addition, the effects of mindfulness meditation on reading speed were examined. Concentration capacity, emotion regulation, and Big Five personality traits were assessed as covariates. A mindfulness group (MG) practiced mindfulness meditation for 2 hr per week over 6 weeks. The control group (CG) studied for university classes during the same periods. Before and after the intervention/control condition, participants completed a standardized assessment of reading comprehension and reading speed, along with tests of concentration ability and emotion regulation. We hypothesized that mindfulness meditation would lead to better reading comprehension and that the active control condition would not change reading performance. Further hypotheses were that individuals' reading speed would improve after the 6-week course in mindfulness meditation. We expected that participants in the MG would increase their attention skills and improve emotion regulation. For the CG, no significant changes in attentional performance and emotion regulation were expected.

Method

Participants

Undergraduate students from the University of Wuppertal took part in the present study. All of them were German native speakers. Half of them participated in the MG (total 26, 23 female, 3 male, 18–32 years of age, $M_{age} = 20.92$, $SD_{age} = 3.41$), and the other half in the CG (total 26, 22 female, 4 male, 19–35 years of age, $M_{age} = 20.34$, $SD_{age} = 3.45$). Groups did not differ significantly in both age $t(25) = 0.59$, $p = 0.28$ and gender $t(25) = -0.4$, $p = 0.35$. To ensure random assignment to the two groups, participants were told that the mindfulness course and the study group (active control condition) would take place in two different time slots in the morning of the same day. They were asked to sign up for one time slot without knowing at which time the mindfulness intervention and at which time the active control condition would take place. Our sample size of $n = 52$ is comparable to Mrazek et al. (2013), who found effects of meditation on reading comprehension in a study with 48 participants. Inclusion criteria comprised no previous meditation experience, no history of psychiatric disorders, and no reading and writing difficulties.

Procedure

For the pre-test, all participants first completed the reading speed and comprehension test, then the attention test, the emotion experience test, the vocabulary intelligence test, and the Big Five personality test. Starting the following week, participants, who had signed up for Time Slot A participated in a 6-week mindfulness course, participants, who had signed up for Time Slot B participated a 6-week study group. One to 5 days after the end of the intervention/control condition, all individuals participated in the post-test, completing the reading speed and comprehension test in a parallel form, the attention test, the emotion experience test, and the Big Five personality test.

For 6 consecutive weeks, both the mindfulness intervention and the control active condition were held in the morning on the same day of the week. An experienced meditation trainer led the meditation group. For the CG, an undergraduate assistant monitored that the participants worked silently for a university class. Each mindfulness meditation session lasted 2 hr and consisted of a 15-min welcome and setting up the necessary materials together (mats, sitting aids…), followed by a 30-min explanation of the meditation technique to be practiced in that session, discussion, and answering questions. Then participants for 25 min followed a guided sitting meditation, a 15-min guided walking meditation, and again a 25-min guided sitting meditation. The last 15 min was used for answering any remaining questions and cleaning up the aids. Table 1 contains information about the course content of each session. The active control condition was designed to involve participants in a silent and mentally active way that resembled their usual day-to-day activities. The participants of the present study were all undergraduate students; therefore, we selected a silent study group as an adequate active control condition. Participants were recruited via online advertisements. For their participation, individuals received course credits. All participants signed a written informed consent form prior to their participation in the study.

Table 1. Mindfulness class protocol

Week	Course contents
1	Introduction to suitable sitting postures for meditation, the body scan (relaxation method of the body), and walking meditation.
2	Introduction of various techniques to achieve continuous concentration on the breath.
3	Mindful awareness of the breath, physical sensations, emotions, and thoughts. Calming the mind.
4	Being in the present moment without being carried away by physical sensations, emotions, and thoughts. Staying in silence.
5	Learning not to evaluate the encounters of the present moment as good or bad or identify with them, but to see them in a neutral way and let them go.
6	Consolidation of the techniques learned.

Measures

Attention Test

An attention test ("d2-Revision test") was used to assess the ability to focus on task and the participant's sustained attention. Under time pressure, the letter "d" with two marks is to be found among similar-looking distractor letters. The test contains 57 items. The two scales "number of processed target objects" and "concentration capacity" demonstrated Cronbach's alpha values between $\alpha = 0.89$ and 0.95, and the scale "percentage of errors" values between $\alpha = 0.80$ and 0.91. Empirical evidence for criterion and construct validity was reported by the authors (Brickenkamp et al., 2010).

To assess the internal consistency of the data of the present study, McDonald's omega (ω) and Cronbach's alpha (α) were calculated for the used test scales. All following interpretations of the internal consistency of the data of the present study are based on McDonald's omega values. All scales of the attention test demonstrated very good internal consistency ("concentration capacity" $\omega = 0.96$, $\alpha = 0.92$; "percentage of errors" $\omega = 0.93$, $\alpha = 0.86$; "number of processed target objects" $\omega = 0.97$, $\alpha = 0.96$).

Emotion Experience Test

The emotion experience test ("Skalen zum Erleben von Emotionen") that we used consists of 42 items and the 7 scales: "acceptance of one's own emotions", "experiencing emotion overload", "experiencing lack of emotions", "body-related symbolization of emotions", "imaginative symbolization of emotions", "experience of emotion regulation", and "experience of self-control". The assessment is intended to reflect how people evaluate, perceive, and deal with their feelings. The scales demonstrated an internal consistency between 0.70 and 0.86 (Cronbach's alpha). Retest reliability was in a range of 0.60 to 0.90 across measurement time points of 2, 3, 4, 10, and 14 weeks for all scales (Behr & Becker, 2004).

In the present study, six of the seven scales of the emotion experience test showed good internal consistency ("acceptance of one's own emotions" $\omega = 0.88$, $\alpha = 0.83$; "experiencing emotion overload" $\omega = 0.90$, $\alpha = 0.85$; "body-related symbolization of emotions" $\omega = 0.87$, $\alpha = 0.81$; "imaginative symbolization of emotions" $\omega = 0.87$, $\alpha = 0.79$; "experiencing lack of emotions" $\omega = 0.84$, $\alpha = 0.79$; "experience of self-control" $\omega = 0.89$, $\alpha = 0.84$). An item example for "acceptance of one's own emotions" is "I stand by my sentiments". One scale showed acceptable internal consistency ("experience of emotion regulation" $\omega = 0.71$, $\alpha = 0.64$). An item example for the scale "experience of emotion regulation" is "When I get nervous, I usually know how to calm myself down".

Big Five Personality Test

The Big Five personality test measures personality traits as captured in the Big Five model of personality with 72 items. In addition to the original five scales, "Neuroticism" (Cronbach's alpha, $\alpha = 0.90$), "Conscientiousness" ($\alpha = 0.77$), "Extraversion" ($\alpha = 0.87$), "Agreeableness" ($\alpha = 0.76$), and "Openness to Experience" ($\alpha = 0.76$), the revised version added three scales, "Need for Power and Influence" ($\alpha = 0.78$), "Need for Security and Peace" ($\alpha = 0.84$), and "Need for Achievement and Performance" ($\alpha = 0.82$). The test showed good factorial validity (Satow, 2011).

In the present study, 5 of the 8 Big Five scales showed good internal consistency ("Neuroticism" $\omega = 0.90$, $\alpha = 0.86$; "Extraversion" $\omega = 0.92$, $\alpha = 0.88$; "Need for Power and Influence" $\omega = 0.85$, $\alpha = 0.73$; "Need for Security and Peace" $\omega = 0.91$, $\alpha = 0.85$; "Need for Achievement and Performance" $\omega = 0.86$, $\alpha = 0.76$). An example for an item for the scale "Neuroticism" is "I am often sad for no reason". Three Big Five scales showed acceptable internal consistency ("Conscientiousness" $\omega = 0.79$, $\alpha = 0.70$; "Agreeableness" $\omega = 0.77$, $\alpha = 0.68$; "Openness to Experience" $\omega = 0.71$, $\alpha = 0.58$). An item example for "Conscientiousness" is "I have my principles and stick to them".

Reading Speed and Comprehension Test

To assess reading comprehension and reading speed, participants completed randomly assigned parallel versions of a German reading speed and comprehension test ("Lesegeschwindigkeits- und Verständnistest") at the beginning of the study (Schneider et al., 2017). For this assessment, participants have to read a text as far as they can within 6 min. Reading speed is measured by the number of words read. While participants read the text, they also have to complete a cloze test to evaluate their reading comprehension. Every 4–7 lines, there is a square bracket in the text that contains three words. The participants have to decide which of these words fit the context of the text; they can edit a maximum of 47 items. Concerning correct, incorrect, and omitted answers, the value of text comprehension is formed using a point system. The used reading speed and comprehension test is widely accepted in German-speaking countries and provided good retest reliabilities, with *r*-values ranging between 0.72 and 0.89. Correlative analyses with external criteria (e.g., with the reading comprehension test from PISA 2000) provided evidence for convergent and discriminant validity (Schneider et al., 2017).

For the reading speed and comprehension test, it is not useful to assess internal consistency. "Due to the conception of the [reading speed and reading comprehension] test […], the reliability of the LGVT 6–12 is determined via the retest reliability, since the otherwise usual measures such as the split-half coefficient due to Spearman-Brown, [or] Cronbach's Alpha […] cannot be meaningfully calculated, since the differentiation between the students is […] made via […] the number of items solved" (Schneider et al., 2017, p. 17; English translation). Therefore, we did not include Cronbach's alpha or McDonald's omega values for the reading speed and reading comprehension test.

Vocabulary Intelligence Test

In the 37 items of the multiple-choice vocabulary intelligence test, a German word is to be found among four similar pseudoword distractors. Published retest reliability included correlations of $r = 0.95$ after 6 months and $r = 0.87$ after 14 months. Empirical evidence for good criterion validity was published (Lehrl, 2005). Because of the design of the test, reliability is determined by retest reliability. As for the reading comprehension test, the differentiation between the participants is made via the number solved items; therefore, a meaningful calculation of Cronbach's alpha/McDonald's omega is not possible.

Data Analyses

All assessments were analyzed using linear mixed-effects models (LMEs). The calculations were executed with the statistical software environment R (version 4.0.5, http://cran.r-project.org). The library lme4 was used with the lmer function (version 1.1–14, Bates et al., 2015), which fits an LME to the data. “Groups” (MG/CG) and “time” (before/after intervention/control condition) were fitted as fixed effects, as a random effect, we fitted “participants”; in this way, it became possible to handle participant variance more sensitively. The assumption of normality of the residuals was verified by qqplots. Approximately 1% of the data was not used in the calculations because these data points were not in the range of − 3 and 3 standard deviations of the residual error. When we found significant interactions of “group” and “time”, subsequently separate LMEs for each of the two groups were calculated in order to examine in which group the “time” effect had occurred. For the subsequent analyses, Bonferroni corrections were applied. The Bonferroni adjusted alpha level was 0.025 since there were two tests conducted in the subsequent analyses (0.05/2). Only results that survived Bonferroni corrections are reported. We provide estimates of regression coefficients, their standard errors, and *t*-values. On the basis of the Satterthwaite approximation, we provide *p*-values (lmerTest package, version 2.0–36, Kuznetsova et al., 2017). The mediation model was conducted using the lavaan library (version 0.6–11, Rosseel, 2012). McDonald’s omega (ω) was calculated using the psych package (version 2.2.5, Revelle, 2022).

Results

The results of the vocabulary intelligence test revealed that participants in both groups did not differ significantly in baseline verbal intelligence ($t(25) = 1.62$, $p = 0.11$), MG ($M = 25.83$, $SD = 3.35$), and CG ($M = 24.36$, $SD = 3.21$). All other tests were performed before and after the intervention/control condition. Reading comprehension improved after the mindfulness intervention but not after the active control condition (e.g., Fig. 1). Meditators showed more concentration capacity (e.g., Fig. 2) and processed more target objects in the attention test (e.g., Fig. 3) after the meditation intervention.

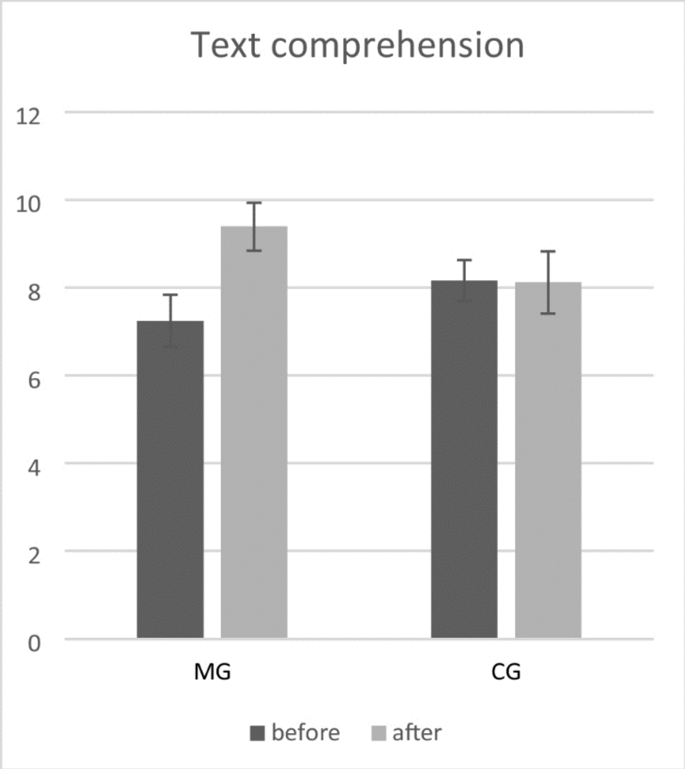

Fig 1. Results of the reading speed and comprehension test, text comprehension. Error bars indicate standard errors

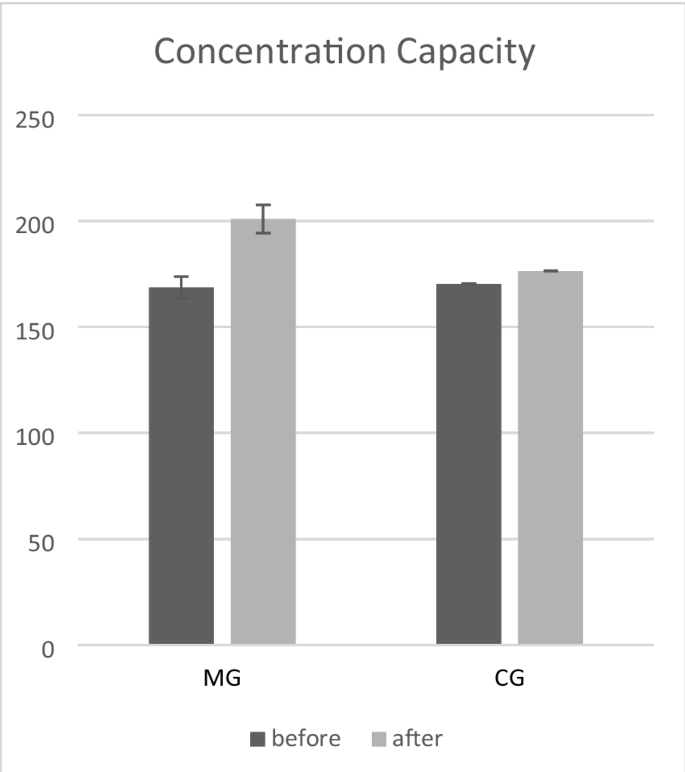

Fig 2. Results of the attention test, concentration capacity. Error bars indicate standard errors

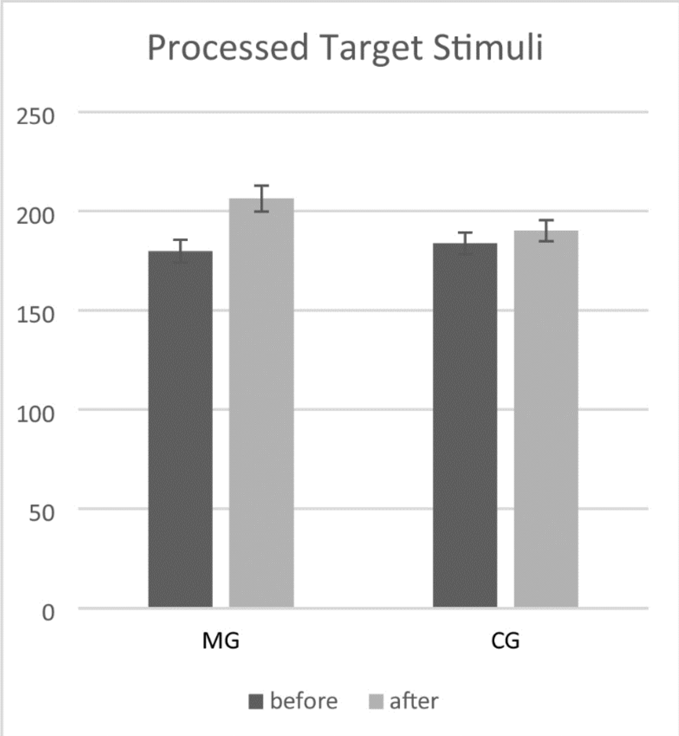

Fig 3. Results of the attention test, processed target stimuli. Error bars indicate standard errors

The LME analyses of the reading speed and comprehension test indicated for the “text comprehension” a significant interaction of “group” and “time”. In a subsequent analysis, we discovered a significant main effect for “time” in the MG, but not in the CG. In the analysis of the attention test data, we found a significant interaction of “group” and “time” for “Concentration Capacity” and “Number of Processed Target Objects”. The follow-up analyses showed for both scales a significant main effect for “time” in the MG, but not in the CG. The analysis of the emotion experience test revealed significant interactions of “group” and “time” for “Acceptance of one’s own Emotions”, “Experiencing Emotion Overload”, and “Body-Related Symbolization of Emotions”. The subsequent analyses showed for all three scales significant main effects for “time” in the MG, but not in the CG (e.g., Table 2 for results of the overall analyses and Table 3 for the subsequent analyses).

Table 2. Overall analysis of assessments: estimates of regression coefficients, their standard errors, t-values, and p-values

Assessments	Fixed effects	*B*	*SE*	*t*	*p*
Reading speed and comprehension test					
Text comprehension	Time	4.34	1.71	2.54	*
	Group	0.92	0.76	1.20	
	Time:Group	− 2.19	1.08	− 2.02	*
Reading speed	Time	26.69	54.29	0.49	
	Group	− 4.44	24.28	− 0.18	
	Time:Group	− 2.50	34.34	− 0.07	
Big Five personality test					
Neuroticism	Time	− 1.44	0.65	− 2.23	*
	Group	0.09	0.29	0.29	
	Time:Group	0.72	0.41	1.77	
Extraversion	Time	0.33	1.01	0.33	
	Group	0.79	0.45	1.77	
	Time:Group	− 0.09	0.64	− 0.14	
Conscientiousness	Time	0.46	1.06	0.44	
	Group	0.31	0.48	0.64	
	Time:Group	− 0.33	0.67	− 0.49	
Agreeableness	Time	0.74	0.83	0.89	
	Group	0.25	0.37	0.68	
	Time:Group	− 0.31	0.52	− 0.59	
Openness	Time	0.58	0.82	0.71	
	Group	− 0.35	0.37	− 0.95	
	Time:Group	− 0.37	0.52	− 0.71	
Need for Power and Influence	Time	0.78	0.92	0.8	
	Group	0.63	0.41	1.53	
	Time:Group	− 0.63	0.58	− 1.08	
Need for Safety and Peace	Time	0.06	0.89	0.72	
	Group	− 0.01	0.39	0.01	
	Time:Group	− 0.56	0.56	− 0.99	
Need for Achievement and Performance	Time	− 0.45	0.87	− 0.51	
	Group	− 0.22	0.39	− 0.55	
	Time:Group	0.14	0.55	0.26	
Attention test					
Number of Processed Target Objects	Time	46.87	13.54	3.46	**
	Group	3.99	8.18	0.49	
	Time:Group	− 20.22	8.56	− 2.36	*
Concentration Capacity	Time	58.51	13.39	4.37	***
	Group	1.66	8.08	0.21	
	Time:Group	− 26.19	8.47	− 3.09	**
Percentage of Errors	Time	− 6.30	2.98	− 2.12	*
	Group	1.45	1.33	1.09	
	Time:Group	2.92	1.88	1.55	
Emotion experience test					
Acceptance of one's own Emotions	Time	2.67	0.72	3.72	***
	Group	− 0.26	1.01	− 0.26	
	Time:Group	− 2.60	1.01	− 2.57	*
Experiencing Emotion Overload	Time	− 3.65	0.79	− 4.60	***
	Group	0.68	1.41	0.48	
	Time:Group	2.45	1.12	2.18	*
Experiencing Lack of Emotions	Time	− 1.79	0.82	− 2.17	*
	Group	0.54	1.05	0.51	
	Time:Group	1.57	1.16	1.35	
Body-Related Symbolization of Emotions	Time	2.37	0.89	2.63	*
	Group	0.32	1.43	0.22	
	Time:Group	− 3.33	1.27	− 2.62	*
Imaginative Symbolization of Emotions	Time	0.43	0.71	0.60	
	Group	− 0.43	1.36	− 0.32	
	Time:Group	− 0.96	0.99	− 0.96	
Experience of Emotion Regulation	Time	0.43	0.46	0.94	
	Group	− 0.69	0.71	− 0.96	
	Time:Group	− 0.27	0.65	− 0.41	
Experience of Self-control	Time	− 0.48	0.64	− 0.75	
	Group	− 0.15	1.17	− 0.13	
	Time:Group	0.51	0.91	0.56	

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. "Time", time effect; "Group", group effect; "Time:Group", interaction of "time" and "group"

Table 3. Subsequent analysis of significant interactions from the overall analysis: estimates of regression coefficients, their standard errors, t-values, and p-values

Assessments	Fixed effects	*B*	*SE*	*t*	*p*
Reading speed and comprehension test					
Text comprehension	MG; Time	2.15	0.62	3.47	**
	CG; Time	− 0.04	0.78	− 0.05	
Attention test					
Number of Processed Target Objects	MG; Time	26.65	5.74	4.64	***
	CG; Time	6.42	6.35	1.01	
Concentration Capacity	MG; Time	32.31	6.33	5.11	***
	CG; Time	6.12	5.63	1.09	
Emotion experience test					
Acceptance of one's own Emotions	MG; Time	2.67	0.77	3.46	**
	CG; Time	0.06	0.66	0.09	
Experiencing Emotion Overload	MG; Time	− 3.65	0.74	− 4.89	***
	CG; Time	− 1.20	0.84	− 1.44	

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

The scales "Concentration Capacity" and "Number of Processed Target Objects" of the attention test and the scales for "Acceptance of one's own Emotions", "Experiencing Emotion Overload", and "Body-Related Symbolization of Emotions" of the emotion experience test changed all significantly after the mindfulness intervention, but not after the active control condition. In further LME analyses, we examined for each of these scales whether they might correlate with the improved reading comprehension in the MG. It turned out that none of the scales of the emotion experience test was associated with reading comprehension, "Acceptance of one's own Emotions" (B = 0.16, SE = 0.31, t = 0.51, p = 0.61), "Experiencing Emotion Overload" (B = − 0.11, SE = 0.22, t = − 0.45, p = 0.62), and "Body-Related Symbolization of Emotions" (B = − 0.26, SE = 0.22, t = − 1.19, p = 0.24). Looking at the attention test, both "Concentration Capacity" (B = 0.06, SE = 0.02, t = 2.10, p = 0.04) and "Number of Processed Target Objects" (B = 0.05, SE = 0.02, t = 2.51, p = 0.02) were positively associated with improved reading comprehension in the MG. Based on these positive associations, we conducted a mediation model to examine whether "Concentration Capacity" or "Number of Processed Target Objects" would mediate the effect of meditation on reading comprehension. Results revealed that neither "Concentration Capacity" (B = 0.18, z = 0.48, p = 0.63) nor "Number of Processed Target Objects" (B = 0.11, z = 0.36, p = 0.72) mediated the effect.

Discussion

In the present study, we found that sustained practice in mindfulness meditation significantly improved reading comprehension. Contrary to our expectations, the meditation intervention did not affect reading speed. No changes in reading comprehension or reading speed were observed in the CG. The MG showed greater acceptance of their emotions, more body-based symbolizations of their emotions, and experienced less emotion overload after the mindfulness intervention. However, these changes in emotion regulation were not positively associated with improved reading comprehension, while the CG did not show any significant differences in emotion regulation. The MG demonstrated enhanced concentration capacity and speed (more targets processed) after meditation intervention. Both scales of sustained attention were positively associated with improved reading comprehension in the MG. However, the analysis of a mediation model showed that enhanced concentration did not mediate the effect of meditation on improved text processing.

Participation in a 6-week mindfulness meditation course resulted in substantially improved reading comprehension. Several underlying mechanisms of meditation may have mediated this effect. There is much evidence that meditation enhances various aspects of attention (Chambers et al., 2008; Semple, 2010; see Lutz et al., 2008 for a review). For example, meditation was found to reduce the Stroop effect (Moore & Malinowski, 2009; Wenk-Sormaz, 2005) and to decelerate binocular rivalry switching (Carter et al., 2005). In the present study, as expected, the ability to concentrate and the number of processed stimuli, as measured by the attention test, were significantly improved after the meditation intervention. Further, both enhanced concentration capacity and the augmented number of processed target objects after meditation intervention were positively associated with improved reading comprehension in the MG. Given that sustained attention is important for successful reading comprehension (Arrington et al., 2014), these results seemed to suggest that improved sustained attention was one of the underlying mechanisms of meditation that contributed to the promotion of reading comprehension in the MG. However, the subsequent mediation model analysis revealed that the effect of meditation on improved reading comprehension was not mediated by either “Concentration Capacity” or “Number of Processed Target Objects”.

An individual with a mind that does not get easily agitated and carried away by arising emotions might have advantages in reading comprehension because it should be easier to focus on the content of the text. Several studies found that meditation training can improve the regulation of emotions (Geschwind et al., 2011; Ivanovski & Malhi, 2007). Therefore, we assumed that emotion regulation could be another underlying mechanism of meditation that might lead to enhanced text processing. Lusnig et al., (2020, 2022) showed that meditation can affect single word processing and also neutralize valence ratings of emotional words. However, in the present study, none of the changes in experiencing emotions was positively associated with improved reading comprehension. This may be related to the fact that, unlike in the word recognition studies of Lusnig et al., (2020, 2022), the text materials used in the present work had no affective connotation and did not call for a substantial affective evaluation.

The present study also did not find effects of meditation practice on the Big Five personality traits “openness” and “need for achievement and performance”. In the study by Lusnig et al. (2020), adept Zen practitioners demonstrated greater “openness to experience” and lower “need for achievement and performance” compared to non-meditators. It seems plausible that people who choose to meditate by themselves are more open to experiences and have a lower need for achievement and performance. In the present study, however, individuals participated in the meditation class for course credits. There is also a possibility of differences between effects of Zen practices vs. mindfulness meditation.

For organizational reasons, we could only include assessments on concentration capacity, emotion regulation, and personality traits as covariates. Given that none of these covariates mediated the effect of meditation on improved reading comprehension, it is interesting to discuss other possible underlying mechanisms of meditation that might account for this effect. Reduced mind wandering might be one of these mechanisms. Several studies found that mind wandering while reading distracts the reader and impairs text comprehension (Reichle et al., 2010; Smallwood, 2011). Feng et al. (2013) found that readers especially struggle with mind wandering when reading difficult texts, and that comprehension of these difficult texts is affected by mind wandering. Mindfulness meditation, on the other hand, can be an effective technique for reducing mind wandering. Both short-term and extended mindfulness meditation practices can decrease mind wandering (Mrazek et al., 2013; Rahl et al., 2017). Further, meditation can lead to a diminished activation of the default mode network, which is associated with the wandering of thoughts (Brefczynski-Lewis et al., 2007; Brewer et al., 2011). This evidence suggests that the reduction of mind wandering (via focusing on the primary task) may be an underlying mechanism of meditation that facilitates reading comprehension.

Another important mechanism for successful reading comprehension, that we could not assess, is a good working memory capacity. Daneman and Carpenter (1980) demonstrated that working memory capacity is associated with comprehension in both silent reading and listening. Working memory capacity is thought to be foundational for reading comprehension "because the processing and storage capacity of working memory is important for remembering new information, for making inferences about new information, and for integrating prior knowledge with the new information" (Daneman & Hannon, 2001, p. 28). A meta-analysis of as many as 77 studies on this topic by Daneman and Merikle (1996) supported the view that a good working memory capacity is important for successful language/reading comprehension. Meditation training was found to be a method for enhancing working memory capacity (Mrazek et al., 2013). Even short-term exercises in mindfulness meditation can increase the working memory capacity (Bonamo et al., 2015; Quach et al., 2016). Further, meditation practice can prevent impairments of the working memory capacity in times of high stress (Jha et al., 2010). It should be noted that the meditation practice employed in the present study used mental imagery techniques to facilitate the achievement of mindful states. Even though we have no data to directly support this idea, it might be the case that this reinforced use of mental imagery might have contributed to successful reading for understanding in the MG, as the use of mental imagery was found to improve reading comprehension (Gambrell & Bales, 1986).

Reading speed can be accelerated through specific reading training without significant loss in comprehension (Radach et al., 2010; Roesler, 2021). Response times to single words can be affected by many different word properties, for example, arousal, frequency, or word length (Hofmann et al., 2009; Kuchinke et al., 2007; New et al., 2006) and are also modified by inter-individual differences between readers (Mueller & Kuchinke, 2016; Siegle et al., 2002). As meditation practice was also found to elicit faster single word recognition (Lusnig et al., 2020, 2022), the question arises of whether meditation training can also influence reading speed of whole texts. This research question is mostly unanswered. Rice et al. (2020) found in a pilot study that mindfulness practice can improve the reading speed of servicepersons in the U.S. military. Both single-word processing and the reading of text passages (the sum of the word reading times) were accelerated. However, in the present study, reading speed did not change after the mindfulness intervention, contrary to our expectations. These incongruent results might be explained by the different reading assessments used in the present study and by Rice et al. (2020). In the study by Rice et al. (2020) a self-paced reading task was used, which did not involve reading entire sentences or text passages in a flow. Words were presented one after another on a computer screen, so that response times were possibly co-determined by motor speed and rhythm. In addition, reading comprehension was not measured in their study. It is therefore possible that their meditation group showed increased single word recognition (as in Lusnig et al., 2020, 2022), but at the expense of comprehension. In the present study, reading speed did not accelerate, presumably because the readers also focused on good text comprehension during a standardized reading test, measuring reading for meaning within a certain time limit.

Several studies showed that decoding of single words and semantic processing (of texts) are separate processes (Golinkoff & Rosinski, 1976; Stothard & Hulme, 1995). For example, children, which have reading comprehension difficulties may decode single words well but are significantly weaker in semantic processing than an age-matched control group (Nation & Snowling, 1998). Carroll et al. (2014) found that children who had a family risk of developing dyslexia were significantly more likely to have difficulty with reading accuracy, but were not at higher risk of developing impaired reading comprehension. In a longitudinal study by Oakhill et al. (2003), two different measures of word reading could not explain reading comprehension differences. This could explain why the meditators of the present study demonstrated better reading comprehension but no improved reading speed. These results also fit with the assumption that meditation increases the depth of information processing (Van Leeuwen et al., 2012). Even though meditators can process single words faster than control participants, this faster single word recognition might not lead to a faster reading performance of texts, because their deeper information processing requires more time. The deeper information processing then might lead to improved reading comprehension.

Limitations and Future Research

The present study reveals some limitations. The sample size was chosen to be similar to a reference study by Mrazek et al. (2013); however, it is relatively small. In the current study, we wanted to conduct post-tests as soon as possible after the intervention/control condition to capture the immediate effects of meditation practice. We chose paper-and-pencil tests because this allowed participants to be tested more quickly in larger groups than with computerized tests. However, especially for the assessment of attentional skills, computerized tests would have been more accurate than the attention test that we had used.

The present study investigated the influence of meditation on reading comprehension and reading speed. Our results suggest that meditation can be a promising technique to improve reading comprehension since meditation is quite easy to learn and can be used everywhere. Based on our results, future studies should utilize more refined methods such as eye tracking to examine the effects of meditation on moment-to-moment processing during reading, along with comprehension on the local and global level (Radach & Kennedy, 2013). A promising candidate for this endeavor is the process of comprehension monitoring, providing a measure of sensitivity towards subtle semantic inconsistencies within text passages (Vorstius et al., 2013). This could provide a possibility to test the hypothesis that skills in mindfulness meditation might have the potential to translate into a deeper and more attentive reading for meaning. Further, future studies on the present topic should consider assessments on mind wandering and working memory capacity, as these may be important underlying mechanisms of meditation that can affect reading comprehension.

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Ethics declarations

Ethics Statement

The study, which was conducted for the present article, followed the ethical standards of the Declaration of Helsinki and the German Society of Psychology (DGPs). The Ethics Committee of the University of Wuppertal reviewed the experiment and approved it.

Informed Consent

Informed consent was obtained from all participants included in the study.

Conflict of Interest

The authors declare no competing interests.

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7 General Discussion

The following section summarizes the findings of the three experimental studies that have been incorporated into the present doctoral thesis and relates them to the context of the current state of research. Strengths and limitations, practical implications, emerging open questions, and the need for future research are then outlined. The section closes with a conclusion.

7.1 Summary of results

Meditation is an ancient technique that can take many different forms. Zen and mindfulness meditation serve, among other things, to focus and calm the mind. Loving-kindness meditation additionally aims at cultivating compassion towards oneself and others. The present doctoral thesis examines whether these three types of meditation have an influence on the processing of affective single words, reading comprehension, and reading speed.

The **first study** examined whether a 90-minute Zen meditation session had an impact on the valence ratings of (low-arousal) positive, low- and high-arousal negative, and neutral German nouns (stimulus set from Hofmann et al., 2009). It also examined whether the meditation session would affect the processing of these words in an LDT. To control for individual differences between the Zen and comparison group and a possible influence of these differences on the results, participants were tested for intelligence, concentration ability, and personality traits. Regarding personality traits, the Zen group showed a higher "openness to experience" and a lower "need for achievement and performance" than the comparison group at baseline. All other covariate tests revealed no significant group differences. "Openness to experience" and "need for achievement and performance" were included in the valence rating and LDT analyses, but did not affect the main results.

After the 90-minute Zen meditation, the meditators rated positive, low-, and high-arousal negative words more neutral than before the meditation. The comparison group did not show significant differences in the valence ratings after the comparison intervention. While valence ratings target the explicit evaluation of words, the LDT can be used to measure the implicit affective evaluation of words. Regarding the LDT analysis, no effects of meditation on the implicit affective word evaluation were found. In both groups, low-arousal negative words were processed significantly slower than neutral words, which replicates a finding by Hofmann et al. (2009). The finding by Hofmann et al. (2009) that high-arousal negative and positive words were processed faster than neutral words was not replicated. The Zen group processed the words in the LDT significantly faster after the meditation compared to their performance before the meditation session. In the comparison group, response times did not differ after the comparison intervention (see also Figure 6 for diagram of results).

In the **second study,** the influence of mindfulness and loving-kindness meditation on affective word processing was examined in meditation novices. In this longitudinal study, participants conducted an LDT and rated the valence of (low-arousal) positive, low- and high-arousal negative, and neutral German nouns before and after a 7-week class in mindfulness, or loving-kindness meditation or a control intervention. The stimulus set was taken from Hofmann et al. (2009)/study one, 200 words and 200 non-words were additionally generated. Possible influences of individual differences between the three groups regarding intelligence, concentration capacity, and personality traits were not found. Contrary to the expectations, none of the meditation interventions resulted in a change in mood states.

Both meditation groups rated the valence of words more neutral after the meditation interventions. Except for positive words, which were rated more positively after the loving-kindness meditation. Valence ratings did not change after the control intervention. In the LDT analysis, no effects of meditation on the implicit affective word evaluation were found. Both meditation groups processed words globally faster after the interventions. This effect was most pronounced after the loving-kindness intervention. The participants of the control group did not demonstrate significantly different response times after the intervention. As in Hofmann et al. (2009) and study one, in all three groups, low-arousal negative words were processed slower than neutral words. The study did not replicate the finding by Hofmann et al. (2009) that high-arousal negative and positive words were processed faster than neutral words (see also Figure 7 for diagram of results).

The **third study** examined whether a 6-week course in mindfulness meditation could improve reading speed and comprehension. As in the first two studies, participants were tested at baseline for intelligence, concentration ability, and personality traits, further, they conducted an emotion experience test. In the third study, participants conducted all baseline tests (except for the intelligence test) also after the interventions in order to examine underlying mechanisms of meditation.

Reading comprehension improved significantly in the mindfulness group after the intervention, but not in the control group. Mindfulness meditation did have an effect on reading speed, contrary to the expectations. No changes in reading speed were found in the control group. After the mindfulness intervention, participants demonstrated less “emotion overload”, more “body-based symbolizations of their emotions”, and “greater acceptance of their emotions”. The control group did not change in emotion regulation scores after the control intervention. Regarding the attention test, participants showed enhanced concentration capacity and processed more targets after the meditation class. In the mindfulness group, enhanced sustained attention was positively associated with improved comprehension during reading. A mediation model analysis, however, showed that enhanced sustained attention did not mediate the effect of meditation on better reading comprehension (see also Figure 8 for diagram of results).

Study 1, diagram of results

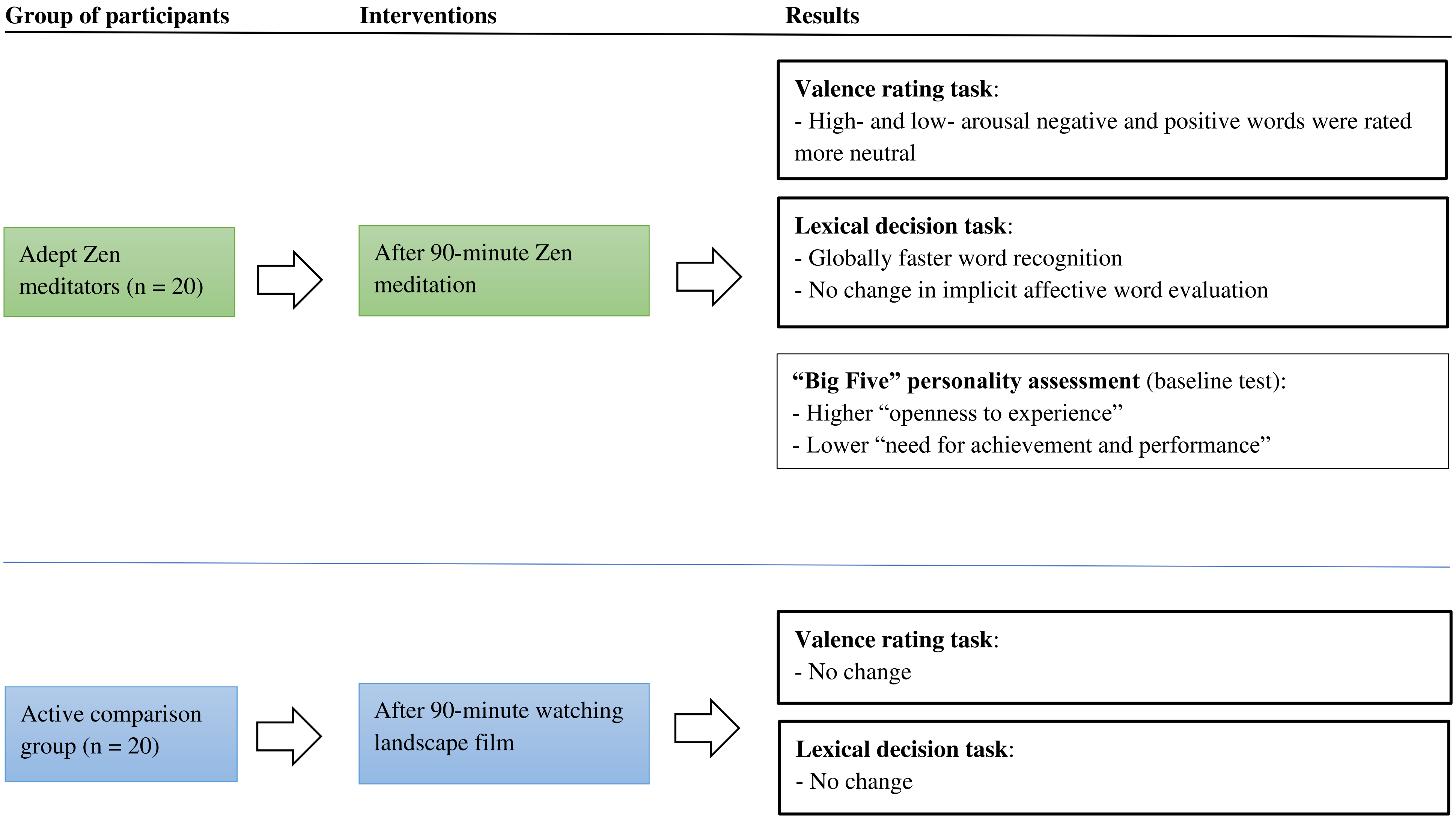

Figure 6. Study 1, diagram of results

Study 2, diagram of results

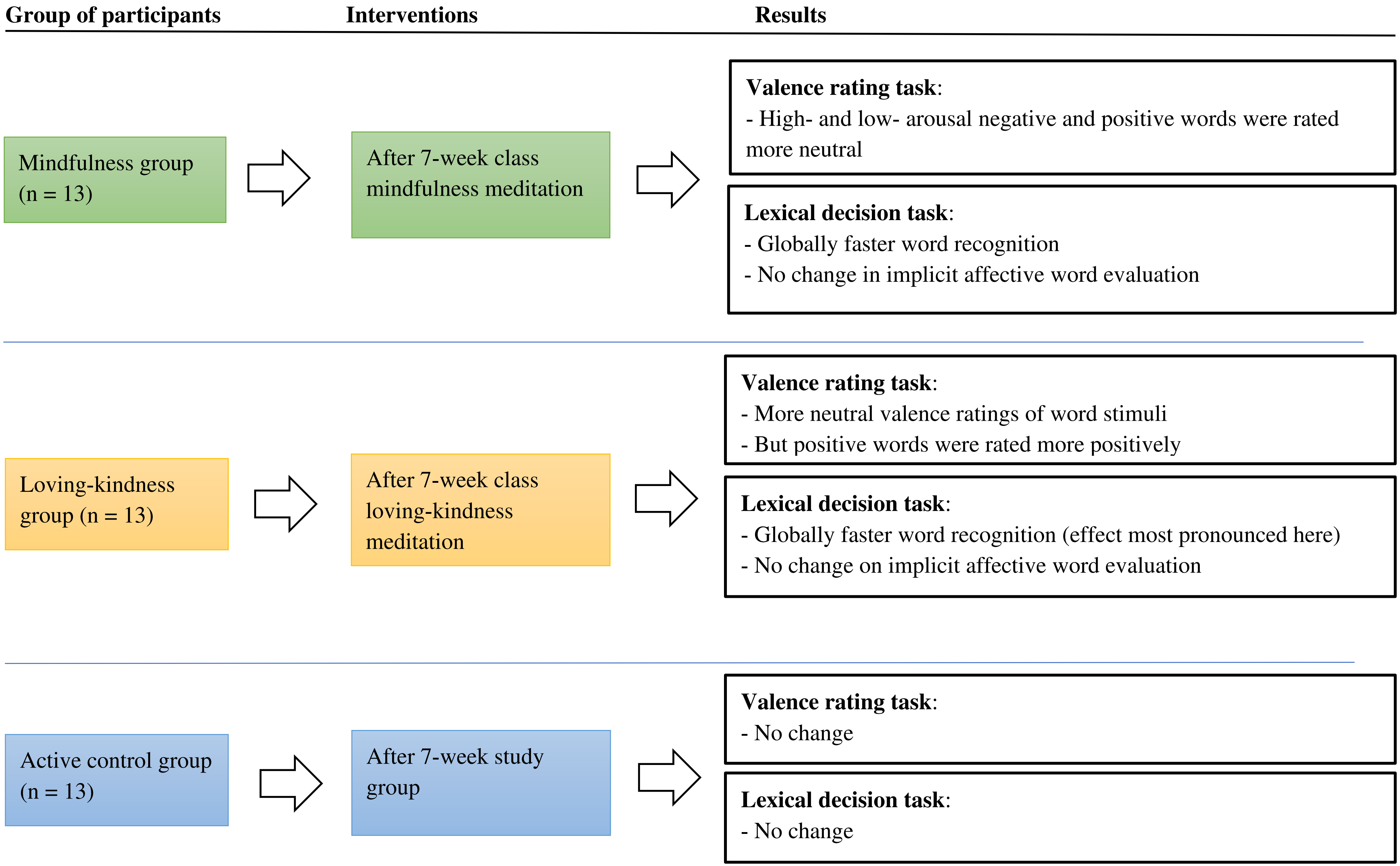

Figure 7. Study 2, diagram of results

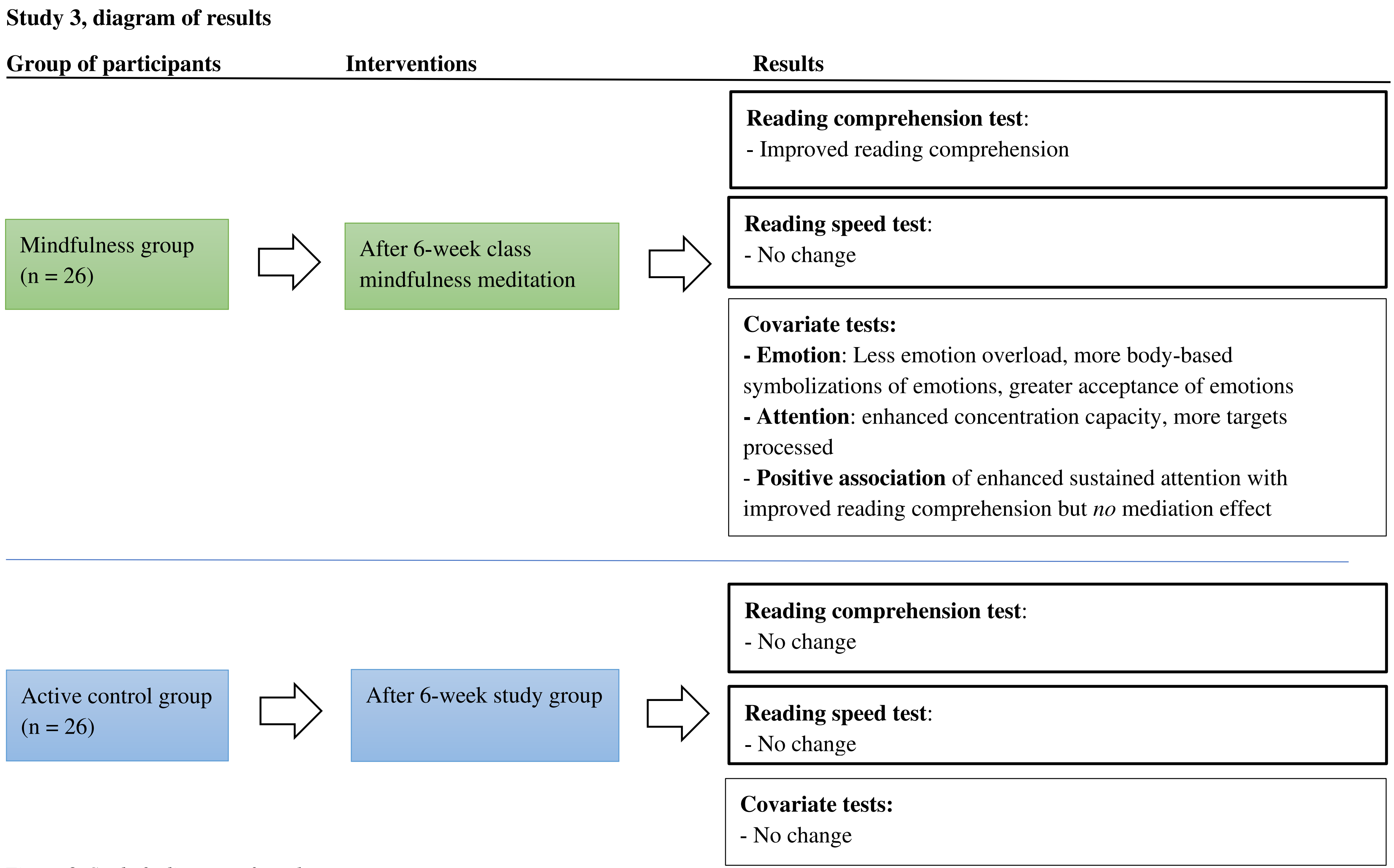

Figure 8. Study 3, diagram of results

7.2 Discussion of key findings and relation to current research

The present doctoral thesis is aimed at examining whether meditation practice has an influence on the processing of affective single words and on reading performance. Summarized in a nutshell, it was found that meditation practice led to more neutral valence ratings of affective single words and to globally faster processing of word stimuli. While the reading speed in continuous texts was not affected by meditation, meditation practice led to improved reading comprehension.

In the following section, the results of the three studies, that were conducted as part of the present doctoral thesis, are discussed in relation to three crucial debates in current meditation research, which partly interrelate. These are the debates on trait- and state changes following meditation practice, dispositional and deliberate mindfulness, and individual differences. This will provide the opportunity to discuss the results in a broader context as in the three published manuscripts and to look at the findings from different perspectives of interpretation. Further, a possible explanation from the field of neuroscience on why meditation affects visual word recognition and reading comprehension is proposed. The section concludes with an examination of the results that are related to the topic of emotion regulation.

7.2.1 Trait- and state changes following meditation practice

For the interpretation of the results of the three conducted studies it is important to differentiate between trait- and state changes following meditation practice. “Traits” can be defined as “characteristic patterns of thinking, feeling, and behaving that generalize across similar situations, differ systematically between individuals, and remain rather stable across time” (Schmitt & Blum, 2020, p. 5206). A definition of “states” can be given as “characteristic patterns of thinking, feeling, and behaving in a concrete situation at a specific moment in time” (Schmitt & Blum, 2020, p. 5206). State changes of meditation practice refer to effects that are only temporary, trait changes relate to relatively stable changes as the alteration of personality traits and emerge after an extensive meditation practice (Tang & Tang, 2017). For example, meditators were found to demonstrate greater congruence between explicit and implicit self-esteem compared to control participants (Koole et al., 2009), which can be interpreted as a trait change. A review by Crescentini and Capurso (2015) concluded that personality (traits) can change through mindfulness practice, even though research in this area is still in its beginnings.

In **study one,** the experienced Zen meditators showed at baseline a significantly higher "openness to experience" and significantly lower "need for achievement and performance" in the Big Five personality assessment compared to the comparison group. This result can be interpreted as a trait change following a long-term practice of Zen meditation. Further, the result is in line with a study by Pokorski and Suchorzynska (2017), which associated Zen meditation practice with the Big Five personality dimension "openness to experience".

After a 90-minute meditation session, the Zen group demonstrated significantly faster word recognition in an LDT than before the meditation. Response times in the comparison group did not change significantly after the comparison intervention. Participants performed the LDT immediately after the meditation session. This effect can be interpreted as a state change following meditation practices since the Zen group demonstrated only temporarily faster word recognition. Otherwise, the response times should have been at baseline as fast as after the meditation session or faster than the response times of the comparison group. In a study by Pagnoni et al. (2008), adept Zen meditators performed an LDT *during* a meditative condition and did not demonstrate different response times compared to control participants. However, their finding that Zen meditators and control participants did not differ in word recognition speed may have resulted from the fact that Zen meditators in their study had to transition constantly from focusing on the breath to focusing on word stimuli. This procedure may have been time-consuming.

Hofmann et al. (2009) reported that low-arousal negative words were processed significantly slower than neutral words. In study one, this effect was replicated in the Zen and the control group and it is also in line with the approach-avoidance model (cf. Citron et al., 2014a; Robinson et al., 2004). The finding by Hofmann et al. (2009) that high-arousal negative and positive words were processed faster than neutral words was not replicated in studies one and two. That might be because participants in the study by Hofmann et al. (2009) underwent different external conditions. The electrode preparation in their EEG study may have induced a small level of exertion in participants that enhanced the positive and high-arousal negative word effects.

In **studies one and two**, after the meditation session/classes, meditators rated words more neutral than before the meditation interventions. The comparison group of study one and the control group of study two did not show significant differences in the valence ratings after the interventions. These effects can be interpreted as temporary state changes following meditation since the valence ratings of the adept meditators in study one were less neutral before the meditation session, which shows that it was not a trait change. While studies on the effect of meditation on word valence ratings are rare, Desbordes et al. (2012) reported a similar finding, which is that meditation decreased the affective impact of emotional images.

Regarding the **second** and **third studies**, it can be assumed that all effects found following the meditation interventions are state changes. The effects seem to have a certain consistency since the meditation courses had already ended a few days before the post-tests. It is reasonable to assume that without further meditation practice, the effects would regress to baseline levels, but only follow-up tests could provide certainty on whether state or trait effects were measured.

In **study two,** both, the mindfulness and the loving-kindness group demonstrated faster word recognition after the meditation interventions. The control group did not show significantly different word processing after the control intervention. This effect replicates the finding from study one that meditation facilitates word processing. The greatest speedup in word processing was found after the loving-kindness intervention. Loving-kindness meditation aims to cultivate positive feelings towards oneself and others. Fredrickson and Branigan (2005) reported that positive feelings can lead to a broader attentional focus, which in turn can support improved performance on an attentional task (Willems & Martens, 2016). This might explain the particularly fast word recognition in the loving-kindness group. In a study by Hofmann et al. (2009) and in study one, low-arousal negative words were processed slower than neutral words. In the second study, this effect was replicated in all three groups.

Since meditation was found to lead to accelerated word processing in studies one and two, a faster reading speed was expected for **study three**. However, the mindfulness intervention had no effect on reading speed. Reading speed also did not change in the control group after the intervention. A pilot study by Rice et al. (2020) reported that mindfulness exercises improved the reading speed of military recruits. This study utilized a self-paced reading assignment that did not require reading complete sentences or passages of text in a continuous flow and did not measure reading comprehension. While it could be that the processing of single words accelerated at the expense of reading comprehension in the study by Rice et al. (2020), participants in the third study may have focused on good reading comprehension at the expense of reading speed.

To date, few studies have examined possible effects of meditation training on reading performance, and they have not found consistent results. In a study by Linden (1973), participants' reading comprehension did not improve after an 18-week meditation class. A pilot study by Benney et al. (2021), which examined the impact of mindfulness meditation practice on reading fluency, could not find conclusive evidence in various data analyses on whether meditation affects reading fluency. Zanesco et al. (2016), on the other hand, found that meditation interventions led to faster detection of semantic inconsistencies in a self-paced reading task. The third study addressed these inconclusive results and found that reading comprehension improved in the mindfulness but not in the control group following the interventions. In addition, after the meditation intervention, the mindfulness group showed enhanced sustained attention, which is in line with other studies (Chambers et al., 2008; see Lutz et al., 2008 for a review). Enhanced attentional capacity was associated positively with the improvement in reading comprehension. However, improved sustained attention did not mediate the effect of mindfulness practice on enhanced reading comprehension. A hypothesis could be that instead other underlying mechanisms of meditation, like reduced mind-wandering (Mrazek et al., 2012) and improved working memory capacity (Quach et al., 2016), may mediate this effect.

7.2.2 Dispositional and deliberate mindfulness

The paragraph above was concerned with the distinction of the *effects* of meditation practice in state and trait changes. The present paragraph addresses the distinction of two different *types* of mindfulness.

In current research on meditation, the focus is no longer only on the study of meditation practice (deliberate mindfulness). In recent years, an increasing number of studies have also examined dispositional mindfulness (see Karl & Fischer, 2022 for a review). Deliberate (intentional) mindfulness refers to a learned or cultivated form of mindfulness, a state of awareness in which the attentional focus is on moment-to-moment phenomena (Dane, 2011). Dispositional mindfulness, on the other hand, refers to the frequency, intensity, and duration with which a person tends to experience mindfulness states (Hülsheger et al., 2013). It concerns someone’s predisposition to experience mindfulness states in everyday life without necessarily having learned to be mindful.

The degree of dispositional mindfulness is generally assessed using self-assessment questionnaires like the Mindful Attention Awareness Scale (Brown & Ryan, 2003), the Five Facet Mindfulness Questionnaire (Baer et al., 2006), or the Kentucky Inventory of Mindfulness Skills (Baer et al., 2004). A clear distinction between the effects of dispositional and deliberate mindfulness in current research is seen as important (Tang & Tang, 2017; Wheeler et al., 2016), although, there are also critical perspectives on the measurement tools of dispositional mindfulness (Park et al., 2013; Grossman, 2011).

The research debate on this distinction is mostly about mindfulness and therefore concerning mindfulness meditation. However, the facets that are assessed for dispositional mindfulness (acting with awareness, observing, nonjudging of inner experience, nonreactivity to inner experience, and describing; Baer et al., 2006) play also a part in other meditation styles, like Zen or loving-kindness meditation. Therefore, in the following, the terms dispositional and deliberate mindfulness will be used as collective terms for different styles of meditation. All three studies of the present doctoral thesis were designed to examine possible effects of deliberate mindfulness on word processing and reading performance and should be interpreted in this way. Dispositional mindfulness scores were not assessed in the three studies. However, for the interpretation of the results of the three studies, it is important to note that the dispositional mindfulness of the participants could have influenced the findings and that the inclusion of this variable could have led to further results.

Since it was found that meditation training leads to increased dispositional mindfulness (D'Antoni et al., 2022) it could be assumed that the participants of the Zen group of the **first study** already had a high dispositional mindfulness at baseline. Thus, the findings of study one could also be interpreted taking this into account. At baseline, the Zen group showed in the Big Five personality assessment a significantly higher "openness to experience" and significantly lower "need for achievement and performance" than the comparison group. A meta-analysis by Giluk (2009) showed that dispositional mindfulness and Big Five personality dimensions are correlated. This meta-analysis of 29 studies demonstrated that dispositional mindfulness is negatively correlated with the Big Five personality dimension neuroticism and positively correlated with the dimension conscientiousness. Keeping this in mind, it seems plausible that the high "openness to experience" and the low "need for achievement and performance" might be effects of a high dispositional mindfulness of the Zen meditators in the first study. As described in paragraph

7.2.1 this effect can also be interpreted as trait-level change following a long-term meditation practice. Here these two concepts interrelate. For all other baseline tests, no group differences were found.

Participants in the **second** and **third studies** (longitudinal studies), who already had a high dispositional mindfulness at baseline may have benefited more from the meditation classes than participants with low dispositional mindfulness at baseline. Furthermore, if participants in the control group might have demonstrated excessively high or low dispositional mindfulness, this may also have had important influences on the study results. Therefore, the measurement of dispositional mindfulness would be recommended in similarly designed future studies.

7.2.3 Individual differences

When interpreting the results of the three conducted studies the research debate on individual differences and their influence in meditation studies has to be taken into account. As in other areas of research involving experimental studies, individual differences can have an impact on the effects found in meditation studies. For example, Ding et al. (2015) demonstrated that creativity improved after a meditation intervention. Lower fatigue, higher anger, and lower depression, which were measured at baseline, predicted better creative performance after a mindfulness intervention. In addition, facets of mood and personality, which were assessed at baseline, explained almost 60 percent of the variance observed in the change in creativity. Hence, facets of mood and personality largely influenced the improvement in creative performance in that study (Ding et al., 2015; Tang & Braver, 2020). A meta-analysis by Buric et al. (2022), which analyzed 51 meditation studies, found that participants with a higher baseline score on psychopathology demonstrated a worsening of psychological health after meditation interventions. In contrast, higher levels of positive meditation outcomes were shown by participants with higher scores on motivation, and mindfulness. These studies indicate that it is important to take individual baseline differences into account in order to understand the mechanisms of meditation interventions.

Furthermore, in meditation research many studies are cross-sectional. These studies have the limitation that a clear causal relationship with the effects of a study cannot be established. It is difficult to distinguish whether an effect has arisen in a group of experienced meditators as a result of meditation practice. The effect could also be an individual difference that was already present in the meditators before they started their meditation practice and may even have been the reason why they were attracted to meditation practice (Tang et al., 2015). Tang and Tang (2017) proposed that in particular, personality, brain structure and function, and genetic conditioning should be taken into account as individual differences that may influence the outcomes of meditation studies.

In the **first study**, covariate tests were assessed at baseline. For intelligence and concentration capacity no significant group differences were found. However, the Zen group demonstrated a higher “openness to experience” and a lower “need for achievement and performance” in the Big Five personality assessment. These two items were included as covariates in the valence rating and LDT analyses but did not have an impact on the main results of the study. The higher “openness to experience” and lower “need for achievement and performance” in the Zen group can be interpreted as a trait-effect of Zen practice and as an effect of their presumably higher dispositional mindfulness, as mentioned above. It is also possible, to interpret the higher “openness to experience” and a lower “need for achievement and performance” as individual differences, that were already present in the meditators before they started meditating. Maybe their higher “openness to experience” was partly responsible for their attraction to meditation practice. In study three, none of the personality dimensions from the Big Five assessment changed after any of the interventions, this could also be an indication for this interpretation.

For **all three studies**, the data was analyzed using linear mixed-effects models. Using this method, the impact of individual differences could be reduced. At the subject level, variability within the groups was taken into account by fitting “participants” as a random effect. In **studies one and two**, “word-items” were further fitted as a random effect to take variability within participants on the item-level into account (cf. Kliegl et al., 2011). In **studies two** and **three**, covariate tests that controlled for individual differences in intelligence, concentration ability, personality traits, and emotion experience revealed no significant group differences before the interventions.

When it comes to individual differences, it is not only important to be aware that these can influence the outcomes of meditation studies. The three conducted studies found that meditation affects valence ratings of affective words, speed of word recognition, reading comprehension, attention, and emotion regulation. Therefore, the three studies also show that pre-existing meditation experience should be considered as an individual difference that can affect the outcomes in studies that examine word processing, reading performance, attention, and emotion regulation in other contexts.

7.2.4 Meditation, word processing, reading performance, and the left inferior frontal gyrus

The present doctoral thesis comes to the conclusion that meditation practice has an impact on visual word processing and reading comprehension. A possible answer to the question of why meditation affects word processing and reading performance can be obtained from the field of neuroscience. Among other regions, the left inferior frontal gyrus (LIFG) is a brain region that is often found to be activated during meditation or shows altered gray matter density in long-term meditators. In a magnetic resonance imaging (MRI)-study, Vestergaard-Poulsen et al. (2009) examined possible changes in gray matter density between ten adept meditators and ten age-matched non-meditators. In their study, meditators demonstrated increased gray matter density in the LIFG compared to control participants. Long-term meditators also showed increased activation of the LIFG during meditation compared to a non-meditative state in an fMRI study (Guleria et al., 2013). Davanger et al. (2010) found increased activation of the LIFG in meditators during a meditative state compared to a control state.

The LIFG is not just engaged during meditative states it also contributes to word recognition processes. In an fMRI study by Kuchinke et al. (2005), twenty-two participants performed an LDT with 50 positive, neutral, and negative words each. The inferior frontal gyrus showed bilaterally increased activation during the processing of emotional words compared to neutral words. In another fMRI study, 27 participants conducted an LDT with abstract and concrete words. Results showed that the LIFG demonstrated a greater activation during the processing of abstract words than it did for concrete words (Della Rosa et al., 2018). A study by Forgács et al. (2012) reported that the LIFG had a key function in the process of semantic integration of new-word meanings. Hofmann and Jacobs (2014) re-analyzed the data of Forgács et al. (2012) and examined whether the strength of association, predicted by the Associative Read-Out Model (AROM; Hofmann et al., 2011), could forecast LIFG activation. They found a greater activation in the LIFG when two words were less associated, as simulated by the AROM. Roelke and Hofmann (2020) found in a semantic priming study that the LIFG was functionally more connected to the right IFG, the anterior cingulate cortex, the cerebellum, the hippocampus, the left fusiform gyrus, and the orbitofrontal cortex when the prime and the target stimulus showed a low semantic similarity. Further, the anterior LIFG was reported to be engaged with the modulation of word recognition speed (Zhu, et al., 2015).

The evidence above shows that the LIFG plays an important part in word recognition processes. In addition, it is activated during meditative states and long-term meditation leads to a greater gray matter density in the LIFG (Davanger et al., 2010; Guleria et al., 2013; Vestergaard-Poulsen et al., 2009). Therefore, it could be assumed that in the first two studies of the present doctoral thesis meditators showed accelerated word recognition because they could recruit the LIFG better than non-meditators.

Further, the LIFG plays an important role in appropriate reading comprehension (Buchweitz et al., 2009). It is engaged with predictive inference making during reading comprehension (Jin et al., 2009) and in semantic integration during sentence comprehension (Huang et al., 2012). A meta-analysis with 40 fMRI studies by Martin et al. (2015) showed that the LIFG is part of a neural network that is activated during natural reading and reading-related activities. Heim et al. (2018) conducted an fMRI study and used the Landolt paradigm to separate purely visual from lexical processing. They found that the orthographic processing activated the LIFG along with other brain regions. Taken together, it might be that meditation has an impact on reading comprehension because it activates the LIFG, which also plays an important role in meditative states as well as in reading-related processes.

7.2.5 Mindful emotion regulation and visual word processing

Emotions can be defined as a multilevel system that includes cognitive, corporal, behavioral, and experience-related reactions. These responses are generated by evaluating the relevance of a situation regarding objectives, values, and needs (Braunstein et al., 2017; Cacioppo et al., 2000; Scherer et al., 2001). Ekman and Cordaro (2011) proposed seven emotions that can be classified as basic emotions. These are fear, contempt, surprise, anger, happiness, disgust, and sadness. This classification of basic emotions is widely accepted, however, there are other approaches (cf. Izard, 2011; Levenson, 2011; Panksepp & Watt, 2011). Emotion regulation can be defined as “the processes by which individuals influence which emotions they have, when they have them, and how they experience and express these emotions” (Gross, 1998, p. 275).

Meta-analyses and reviews suggest that meditation practice is an efficient tool for regulating emotions like anxiety (Blanck et al., 2018; Chen et al., 2012; Hofmann et al., 2010) and depression (Blanck et al., 2018; Hofmann et al., 2010) as well as perceived stress (Lo & Wu, 2007). It is also reported that meditation practitioners have a greater ability to regulate their emotions when confronted with affective images (Arch & Craske, 2006). From a psychological perspective, the key mechanisms of mindfulness meditation that promote emotion regulation are awareness of the present moment and an acceptance attitude towards all present moment experiences (Bishop et al., 2004; Farb et al., 2014).

In **studies one and two**, meditation (Zen, mindfulness and loving-kindness) led to more neutral valence ratings of word stimuli. More neutral valence ratings could be interpreted as an indicator that emotion regulation was achieved by practicing meditation. These effects are in line with findings from various studies demonstrating that meditation can increase emotion-regulation (Goyal et al., 2014; Grecucci et al., 2015; Tang et al., 2007). Positive words were rated more positively after the loving-kindness intervention. This effect is consistent with a study by Hunsinger et al. (2013), which shows that practitioners of loving-kindness meditation relate positivity to neutral cues. After the control intervention, valence ratings did not change significantly. Differences in LIFG activation in meditators might be one of the reasons for more neutral valence ratings in the first two studies, considering that the inferior frontal gyrus (IFG) was found to play a part in emotion regulation (Grecucci et al., 2013; Morawetz et al., 2016) as well as in meditative processes (Davanger et al., 2010; Guleria et al., 2013; Vestergaard-Poulsen et al., 2009). In both studies, meditation did not affect implicit emotional evaluation during word processing in the LDTs.

Interestingly, emotion regulation has been related to cognitive control mechanisms (Ochsner & Gross, 2005; Pruessner et al., 2020; Villalobos et al., 2021). Cognitive control "refers to the ability to regulate cognitive processing according to the tasks at hand, especially when these are demanding" (Ferdinand & Czernochowski, 2018, p. 1). Meditation practice was also reported to improve cognitive control (Chan et al., 2017; Hunsinger et al., 2013). Therefore, it is reasonable to assume that meditation affects emotion regulation also via cognitive control mechanisms.

For **study two**, it was hypothesized that meditation would lead to a regulation of mood states since meditation was found to increase emotion regulation (see Blanck et al., 2018; Chen et al., 2012; Hofmann et al., 2010 for meta-analyses and reviews). Contrary to this hypothesis, mood states did not change significantly across time points in any of the groups using a brief assessment, the "Aktuelle Stimmungsskala". Since this finding is not consistent with the literature on meditation and emotion regulation (Blanck et al., 2018; Chen et al., 2012; Hofmann et al., 2010), it is possible that the assessment was not specific or sensitive enough to measure the emotion regulation induced by meditation practice.

In **study three**, a more elaborate test of experiencing emotions was used, the “Skalen zum Erleben von Emotionen”. In this assessment, the mindfulness group showed less “emotion overload”, more “body-based symbolizations of their emotions”, and greater “acceptance of their emotions” after the intervention. In the control group, emotion regulation scores did not change after the control intervention. These results are consistent with other studies on the effects of meditation practices on emotion regulation (Geschwind et al., 2011; Ivanovski & Malhi, 2007) and with the findings of the first two studies that different meditation techniques lead to more neutral valence ratings of affective word stimuli (possible indicator of emotion regulation).

Considering that an emotionally stable mind may benefit when it comes to concentrating while reading continuous texts, it was hypothesized that improved emotion regulation may be an underlying mechanism of meditation practice that could foster better reading comprehension. However, none of the altered emotion experience assessment items were associated positively with improved reading comprehension. One reason for this could be that while affective words were used in studies one and two, the text material in study three did not contain affective connotations and therefore did not require significant affective evaluation. Another reason might be found in the study by Rahl et al. (2017). They reported that a brief mindfulness practice, which included an acceptance mindfulness training, led to the lowest mind wandering compared to a mindfulness training without acceptance condition and to other control conditions. Therefore, the greater “acceptance of one’s own emotions” in meditators of study three might have led to reduced mind wandering. The reduced mind wandering might then have been the main underlying mechanism, which fostered enhanced reading comprehension.

7.3 Scientific benefits and practical implications

The practice of meditation has become widely accepted. Especially with a simple mindfulness meditation, where one concentrates on the breath, or with a yoga meditation, many people had contact or practice it regularly. The first two experimental studies of the present doctoral thesis showed that meditation practice can affect valence ratings of emotional single words and word recognition speed. Valence ratings are often used to assess the affective impact of the stimulus material required for psycholinguistic experiments. Therefore, the present doctoral thesis shows that meditation and yoga practice should be considered as a variable that needs to be controlled for in individuals participating in psycholinguistic studies. This is especially true for experiments that use valence ratings, LDTs, or word stimuli that were selected via valence ratings.

Studies one and two showed that meditation leads to a more neutral evaluation of affective words. A study by Marin et al. (2012) reported that women showed a higher stress reactivity to written bad news than men. Meditation practice might be helpful for individuals, who react stressed to emotionally arousing written texts, such as bad news in newspapers, text messages, or hate speech in social media.

Regarding the question of whether meditation exercises lead to better reading performance, the current state of research is inconclusive (Benney et al., 2021; Linden, 1973; Zanesco et al., 2016). Study three addressed this question and advanced research in showing that meditation training can improve reading comprehension. As the study demonstrated, already a few weeks of training can increase reading comprehension. Therefore, meditation training might be a helpful tool for people with dyslexia. This is demonstrated also by a study by Tarrasch et al. (2016), who found that people with dyslexia showed 19 percent less reading errors after an 8-week class in mindfulness meditation.

7.4 Strengths and limitations

The three experimental studies, that were conducted as part of the present doctoral thesis, contain strengths and limitations. These are discussed in detail in the following section.

In **study one**, a longitudinal study design and a randomized assignment of the participants to the groups was not possible, because adept Zen meditators participated. That is a limiting factor for interpreting the causal effects of meditation on visual word processing. However, the study has the strength that it used a pre-posttest design with a comparison group, that allowed to measure the immediate effects of a 90-minute meditation session.

A major strength of the **second study** is the longitudinal design and that participants were assigned randomly to the different groups. Another strength of the second study is that two different types of meditation were examined. The study comprised a loving-kindness meditation group, a mindfulness meditation group, and a control group. A limitation of the second study is that the mood states assessment used ("Aktuelle Stimmungsskala") was probably not sufficiently specific or sensitive to measure the emotion regulation elicited by meditation practice. As described above, a large number of well-designed scientific studies have found changes in emotion regulation through meditation. Of course, it cannot be excluded that the absence of an effect of meditation on emotion regulation has other reasons, or that the meditation practice in the second study really did not affect the emotion regulation of the participants.

In the **third study**, a much more elaborate emotion assessment ("Skalen zum Erleben von Emotionen") was used. It was found that meditation increased the "acceptance of emotions" and "body-based symbolizations of own emotions", and decreased "emotional overload". The study design was longitudinal and participants were allocated randomly to the groups. Participants of the second and third studies mainly attended the meditation courses to get course credit. This fact might have influenced the results, even though, most of them probably still had a great interest in learning meditation techniques. It could be that meditation would have shown stronger results or, for example, results on reading speed in the third study if participants had shown an innate interest in meditation.

The present doctoral thesis has the strength that it explores a relatively new area of research. In addition, it advances the current state of research by showing that meditation affects reading comprehension and helps clarify previous contradictory findings. It also advances the current state of research by showing that meditation has an impact on the affective evaluation of words.

7.5 Perspectives for future research

Several implications for future research arise from the present doctoral thesis. Since it has been shown that mindfulness meditation affects the reading comprehension of meditation novices, the next logical step would be to examine this finding more thoroughly with a study using eye-tracking methodology while participants are reading texts (see Radach & Kennedy, 2004, 2013; Rayner, 2009; Rayner & Kliegl, 2012; for further information). In this way, possible differences between meditators and non-meditators could be examined concerning oculomotor events like saccades, regressions, and fixations. To investigate the influence of meditation on reading comprehension in more detail, it might be particularly useful to focus on the process of comprehension monitoring, i.e., how well semantic inconsistencies in texts are detected (cf. Vorstius et al., 2013; Kim et al., 2018).

Further, future studies on the influence of meditation practice on word processing and reading performance should include not only two but three measurement time points. The first measurement point should be before the meditation/control interventions, the second directly after the interventions, and the third measurement point after a few months. In this way, it is possible to distinguish better between state and trait effects. At all three time points, dispositional mindfulness should be measured to monitor how high the dispositional mindfulness was at baseline in all groups and if it increased in the meditation group(s). It would also be of interest whether participants, whose dispositional mindfulness values increased strongly through the meditation classes, would show different responses in word processing and reading performance than participants with a low increase in dispositional mindfulness.

As described in detail in the third published manuscript, it is plausible that improved working memory capacity and reduced mind wandering may be key mechanisms of meditation that impact reading comprehension. Therefore, mind wandering and improved working memory capacity should be systematically assessed in future studies, which regard meditation and reading performance. As described above, LIFG activation may play an important role in explaining why meditation affects word recognition and reading comprehension. For future fMRI studies, it would be interesting to test this hypothesis.

The word stimuli used in studies one and two included both neutral and affective words. The studies showed that Zen as well as mindfulness, and loving-kindness meditation led to a more neutral evaluation of affective words. Therefore, it is plausible that affective texts are also processed differently by meditators compared to non-meditators. The text material used in the third study was predominantly neutral. For future studies, it is therefore interesting to examine the influence of meditation on the processing of texts with affective connotations in direct comparison to neutral texts.

The first two studies demonstrated that the practice of different styles of meditation results in faster response times in an LDT. In study two, the loving-kindness group showed the largest word facilitation. In contrast, in study three, reading speed did not accelerate after the mindfulness intervention. It may be interesting to examine in future studies whether loving-kindness meditation leads to a faster reading speed since this style of meditation led to the fastest response times in study two. Interesting would also be to examine whether, regarding different meditation styles, immediate and non-immediate feedback on lexical decisions would lead to different results as it was shown for artificial language learning (Opitz et al., 2011).

7.6 Conclusions

The present doctoral thesis extends the current research discussion on the impact of meditation on word processing and reading performance. This field of research is relatively new and therefore still insufficiently studied regarding several topics.

In the present doctoral thesis, it was found that Zen, mindfulness, and loving-kindness meditation led to more neutral valence ratings of affective word stimuli and to accelerated responses in LDTs. Loving-kindness meditation presented two distinctive features. This form of meditation resulted in more positive valence ratings of positive words and the greatest acceleration of response times in the LDT. These effects might be explained by the particularly strong cultivation of positive emotions during loving-kindness meditation and a resulting broader attentional focus, as suggested by Fredrickson and Branigan (2005).

Mindfulness meditation was found to improve text comprehension during reading but did not lead to a faster reading speed. Further, this meditation style led to improved attentional capacity as well as improved emotion regulation in different dimensions. Neither improved attentional capacity nor enhanced emotion regulation mediated the effect of improved reading comprehension through meditation practice. For future studies, it is suggested that improved working memory capacity and reduced mind wandering should be examined as possible underlying mechanisms of meditation that might mediate the effect on improved reading comprehension. The results were discussed in relation to current debates in meditation research on trait- and state changes following meditation practice, dispositional and deliberate mindfulness, and individual differences. Different possibilities of interpretation were presented.

The findings give relevant indications for studies using psycholinguistic experiments. Previous experience with meditation should be considered as an individual difference that has the potential to significantly alter study results, especially of LDTs, valence rating tasks, or in valence rating based selection of word stimuli. The results also suggest that meditation practice enhances the regulation of emotions that were evoked by affective words. In addition, meditative exercises could be an effective method to support the regular treatment of difficulties in reading comprehension.

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10 Lists of figures and tables

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11 Appendix

List of generated word stimuli for study 2

(In addition to the word stimuli from Hofmann et al., 2009).

Word Stimuli	Condition
Agent	Neutral
Änderung	
Banner	
Beichte	
Bibel	
Dialekt	
Eidechse	
Eintritt	
Fasching	
Fräulein	
Hammer	
Horoskop	
Insekt	
Kette	
Klient	
Klingel	
Kurve	
Ladung	
Larve	
Lehrling	
Lektion	
Lizenz	
Losung	
Lunge	
Menge	
Mitleid	
Motor	

Niere Organ Pilz Pulver Rampe Regent Schnaps Tabak Taktik Test Traktor Visum Wodka Würfel Antrag Kult Verzehr Abwurf Aufgabe Sohle Beihilfe Gekicher Aufzucht	
Album Anruf Appetit Ausflug Balance Bargeld Befreier Befugnis Charme	Positive (low-arousal)

Elch Erbe Erlebnis Floß Freizeit Frisur Fund Gebet Gedicht Geist Girlande Juwel Klugheit Kreisel Lohn Luxus Macher Medizin Miene Mikrofon Mirakel Mythos Optimist Orakel Panda Parfüm Pfote Pokal Privileg Schwein Spende Strauß Tandem Tresor	

Tropen Umtrunk Verstand Zirkus Zuflucht Aroma Jazz	
Abgrund Anfall Arsch Aufstand Aversion Barbar Beben Diagnose Droge Egoismus Falle Flucht Gefahr Geheul Geschrei Hitze Hure Kampf Kanone Ketzer Knebel Konflikt Krokodil Lawine Luder Mahnung	Negative (high-arousal)

Notfall Notwehr Panik Peitsche Piranha Razzia Rivale Scham Schauder Schrei Schwert Sintflut Spinne Spion Spitzel Spott Tragik Träne Tumult Wahnsinn Zahnarzt Zäpfchen Zensur Zynismus	
Aas Abfall Abstieg Abwasser Aufpreis Ausfall Bahre Ballast	Negative (low-arousal)

Beamte Darm Einfalt Fall Galle General Gerede Gesindel Hagel Hexe Hypothek Keule Knochen Kosten Lump Makel Manko Miete Mietzins Moder Morast Motte Negation Niemand Niete Offizier Opium Pfaffe Pfeil Rabe Rechnung Säge Schlinge Schutt	

Tablette Torheit Trampel Unkosten Unlust Verband Witwer Wurm	