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# Introduction

Imagine you are on vacation in a foreign nation. You find yourself on a typical weekly market in the heart of the old town - it is quite loud, there are many odors of unusual food, foreign sounds and incomprehensible language, everything is colorful and stimulates your senses, and the bodies of numerous people in proximity contact you. It is difficult to keep track of your companion between the commotion and numerous distractions, and suddenly she is gone. Focus on her distinctive characteristics - she is wearing a blue shirt and a brown cap - to locate her again. You will be extremely vigilant and focus your concentration on locating those features again, and one of them will capture your eye immediately. How difficult it is to ignore all other impressions! Can we support focusing our attention on the most important environmental stimuli and ignoring the less important ones? This paper addresses this question. In a variety of ways, the monitoring of sensory perception is involved in the active control of our behavior and thinking processes. Among other things, we assess the achievement of our action goals, for example, avoiding an approaching someone. This type of active monitoring is what binds our attention on specific impressions so that we may not notice currently less relevant stimuli. According to Yakobi et al. (2021), mindfulness training has a positive influence on these monitoring processes, which are related to attention. We will investigate the hypothesis whether Yoga as specific mindfulness training influences the control of visual attention via direct influence on executive functions. This would be a case of far transfer and the most interesting form of transfer as it would demonstrate the intervention´s efficacy. Far transfer refers to the generalization of training in one domain to other domains, whereas near transfer can be described as the improvement of skills in a trained domain (Barnett & Ceci, 2002). To clarify the relationship between Yoga and visual attention, this paper first characterizes Yoga and discusses why we assume that Yoga can have any effect on attentional processes. Next, we explain the addressed processes, also referred to as executive functions of attention, and present various theories of attention as an overarching concept. Subsequently, we discuss the relationship between executive functions and visual search, as visual search tasks allow measuring executive functions. Reference is specifically made to two executive functions of attention that we assume can be directly influenced by Yoga practice: Suppression and switching.

## Yoga

Yoga is a set of physical, spiritual, and mental practices of Indian origin consisting of physical exercises and postures, breathing techniques, deep relaxation, and meditation techniques intended to increase mindfulness, self-regulation, and awareness (Büssing et al., 2012). Fundamental to Yoga is the execution of active and passive postures, called *asanas*, which are designed to mobilize and strengthen the body. To do these postures correctly and in a manner that is beneficial to your health, it is crucial to monitor your entire body closely. Imagine standing on one leg while simultaneously managing the alignment of your hips, stretching your hands straight out to either side, and balancing on the soles of your feet. You are meant to use conscious breathing techniques as a support that also want to be monitored – alternating with monitoring the correct execution of the asanas. You must be focused, receptive to body positions and breath equally, and aware of various physical sensations. Yoga, like traditional meditation, is classified as a *mindfulness-based intervention* (MBI). MBIs are recognized to reduce stress and anxiety (Mander & Blanck, 2018) and promote mindfulness (Greeson et al., 2015). Mindfulness in this context refers to "moment to moment, non-judgmental awareness, cultivated by paying attention in a specific way" (Kabat-Zinn, 2015, p.1481). From a research perspective, two types of mindfulness are distinguished: On the one hand, *trait mindfulness* (TM) refers to attention and general attentiveness to current events and experiences (Brown et al., 2007). On the other hand, *state mindfulness* (SM) refers to specific timepoints and is hence less stable (Mesmer-Magnus et al., 2017). Positive effects of MBIs on stress, TM, SM as well as on anxiety reduction and overall well-being, have been found in clinical and healthy populations (Fjorback et al., 2011; Keng et al., 2011; Kiken et al., 2015). In addition, MBIs have been found to enhance cognitive performance, particularly attentional control, and executive functions (Lippelt et al., 2014; Tang et al., 2015; Yakobi et al., 2021). MBIs, such as focused attention meditation and Yoga, entail the practice of alternating between distinct physical processes and mental process monitoring. One distinction between Yoga and classical meditation is that in Yoga, conscious attention to areas of the body is coupled with physical action – for instance, when transitioning between two asanas. Consequently, unlike meditation, there is a special focus on the active physical component. Despite this, the mindfulness component of Yoga still strongly links it to meditation and distinguishes it from other physical exercises such as simple gymnastics. It is already established that conventional meditation has positive effects on cognitive processes, such as executive functions (Lippelt et al., 2014; Tang et al., 2015; Yakobi et al., 2021). But for Yoga, this has not yet been explored. Could such specific switching training for kinaesthetic feedback also be advantageous for switching between settings in more cognitive tasks such as searching for one object versus another? Numerous studies have already demonstrated that executive functions can be influenced and improved by training (e.g., Anguera et al., 2013; Bherer et al., 2008; Davidson et al., 2003; Johann & Karbach, 2020;

Karbach et al., 2017; Kray et al., 2012). In this study, we examined if Yoga can also be used to enhance cognitive functions. For our randomized controlled trial, we used Hatha Yoga, the most widely practiced form of Yoga. Hatha Yoga is of high popularity among the population and of good feasibility for many people. In addition, due to its body-focused nature, it provides a reliable distinction from other mindfulness-based practices, which is essential for our aim of delineating the effects of individual components of MBIs. If the practice of Hatha Yoga could increase cognitive function, it would provide a valuable tool. Yoga is freely available, requires minimal prerequisites, and has beneficial side effects such as enhancing physical health and well-being. However, positive effects on cognitive processes would be of great importance, as they play a role on so many levels: A few instances include studying for an exam, driving attentively in a city, or concentrating on an important conversation in a noisy environment (Diamond, 2013).

## Executive Functions

The aforementioned executive functions, which can be improved through trainings such as meditation, among others, are crucial components of the control of attention. They regulate how specific cognitive processes are controlled and coordinated throughout the performance of complex cognitive tasks (Diamond, 2013) – for instance, to concentrate on a math problem and block out distractions. The use of executive functions is exhausting. It involves actively engaging, such as by avoiding distractions or intentionally directing attention to pertinent information, rather than relying solely on "autopilot." The three core executive functions are *inhibition*, *updating*, and *shifting* (Miyake et al., 2000). Based on this, higher-order executive functions such as reasoning, problem solving and planning are developed (Collins & Koechlin, 2012; Lunt et al., 2012). Inhibition, including self-control (behavioral control) and interference control (selective attention and cognitive inhibition), can be defined as the ability to decrease or totally prevent the interference of stimuli that are not of importance for a demanded task. Updating relates to *working memory* (WM) and involves updating and monitoring of inner representations. Shifting, also called mental set shifting or cognitive flexibility, builds on inhibition and WM and entails the ability to modify one´s spatial or interpersonal perspective. These functions vary among individuals and, as indicated, can be trained via MBIs (e.g., Anguera et al., 2013; Bherer et al., 2008; Davidson et al., 2003; Johann & Karbach, 2020; Karbach et al., 2017; Kray et al., 2012). However, effects on updating could not be confirmed in a recent meta-analysis (Yakobi et al., 2021), therefore in our experiment, we only investigated functions for which there is evidence that they can be influenced by MBIs: Inhibition and shifting.

## Attention

Executive functions such as inhibition and shifting have been described as essential tools of *attention*. Attention has been identified as a cognitive function that aids in navigating our chaotic environment and completing tasks in a goal-directed manner (Carrasco, 2011; Schoeberl & Ansorge, 2017). But exactly how is this made possible? There are several perspectives on this. Attention is understood here as functional selectivity of perception and information processing that enables individuals to monitor the success or failure of actions and cognitive processes, hence enabling goal-directed behavior. The idea of attention as selectivity is originally based on the *filter model* of Broadbent (1958). It is not a mechanism, but rather a description of serveral types of selectivity of perception. For instance, visual attention refers to selectivity in visual perception. To locate your travel companion, you do not take in all the visual stimuli at the weekly market but try to filter out the ones that are relevant to you and only pay attention to color stimuli that match the color of your friend's shirt to find her again. A rationale for explaining the origin of selective attention is the *capacity theory* or *resource theory*. It suggests that perception must select due to limited mental capacities, as processing everything would be impossible due to lack of perceptual resources. This is also called *deficiency theory of perception*. Another idea is the *selection-for-action theory*, in which selectivity, which enables actions, is required not due to a lack of mental resources but rather due to the physical limitations of humans. By concentrating on one flower at a time, for instance, you can collect a bouquet of flowers from a mountain meadow. Even though you can perceive more than two at once, you cannot pick them all at once because you only have two hands (Allport, 1987).

Selection-for-action, that is, filtering information from the environment for planning goal-directed action, is assumed to be one of the two main functions of visual attention (Allport, 1987). Another function is *selection-for-perception*, which relates to the filtering of information, such as to enable environmental comprehension or identification of objects (Posner, 1980). It is referred to as *attentional capture* when processing of environmental stimuli and thus visual attention follows priorities resulting from stimulus attributes (Theeuwes, 1992). Whether this attentional capture is exclusively controlled by certain properties of the environmental stimuli, can be influenced by the recipient, or is based on a mixture of both, still remains unclear (for a review, see Theeuwes, 2010) and will be discussed in detail in a later section. In this paper, two distinct attention systems are assumed. One is *goal-directed attention* (Posner & Petersen, 1990; Yantis, 1998), in which attention is actively directed from top-down, that is, a strategic, volitional control that focuses on particular aspects of the environment in order to achieve current goals (Schoeberl & Ansorge, 2017). It is considered that stimuli that relate to current action goals are assumed to attract attention. The other system is referred to as *bottom-up attention* (Corbetta & Shulman, 2002; Posner, 1980), which is controlled by environmental stimuli and automatically activated by their occurrence, such as when there are no current action goals, or when stimuli are particularly salient. Physically salient stimuli in the visual domain are characterized by local feature differences in color, orientation, and luminance, that is, brightness (Itti & Koch, 2001; Theeuwes, 1992). These two types of attention can be actively regulated by executive functions. Returning to our original example makes it simpler to comprehend the relevance of this. To locate your travel partner at the weekly market, you will focus your attention on the precise color of her clothes or the shape of her hair. Shifting enables you to direct your attention to the shape and color you are looking for. You may be distracted by eye-catching stimuli, such as the flash of a glittering gold hat, since it stands out particularly from its surroundings due to strong contrast and automatically captures your attention regardless of your behavioral goals. Despite this, inhibition permits you to concentrate on the stimuli you are seeking.

## Visual Search

The function we derive benefit from at the weekly market is called *visual search*. This is a cognitive process in which executive functions are employed in an attempt to locate a target stimulus among many task-irrelevant, that is, distractor stimuli. Typically, there is a relevant target stimulus that differs from irrelevant distractors in one or more feature dimensions (Wolfe, 2020). This means that the target has a different color than the rest of the elements or contains a certain combination of color and shape (Verghese, 2001). Imagine you had to find a blue cap among lots of brown hats, for instance. The fact that you have to search for the target of a visual search even though it is in the current field of view is due to basic limitations of visual processing that make it impossible to perceive everything consciously at once (Verghese, 2001). Whether visual search involves serial processing steps for the distinct elements of perception or is a parallel process is still a matter of discussion. Classical theories of selective attention suggest that attention is serially deployed to locations during visual search and consists of two phases (Treisman, 1988; Treisman & Gelade, 1980; Wolfe, 1994): A preattentive, parallel, capacity-unlimited phase in which a representative map of the salience of various stimuli is created, and a capacity-limited phase in which attention is used to serially identify objects on the salience map. For instance, according to *feature integration theory* (Treisman & Gelade, 1980), the type of search also depends on whether a target stimulus is to be distinguished from distractors by a unique feature (parallel search) or whether combinations of multiple features are required to differentiate the presented objects (serial search). To understand better: In the serial case, visual search task search times would rise proportionally to the amount of elements to be processed. In contrast, in *single-stage theories*, attention is evenly distributed across all stimuli, which are then processed simultaneously; therefore, search times would not increase (Carrasco et al., 2004; Eckstein et al., 2000; Palmer, 1995; Palmer et al., 2000; Verghese, 2001; Ward & McClelland, 1989). In this account, search times would be always independent of the quantity of to-be-processed items.

The concept of internal representations of visual inputs is shared by competing hypotheses. In their *similarity theory,* Duncan and Humphreys (1989) define search templates, which are formed internally and represent target stimulus features against which visual stimuli are compared during search. Distractors that resemble the template, and hence the target stimulus (that is, a *target-similar distractor*), increase search time because it takes longer to perceive them as distractors. Unless all features can be searched simultaneously, the template must be updated throughout the search. The idea of the search template will occupy us further when it comes to the shifting function in detail. Another parallel theory based on the idea of internal representation is the *signal detection theory*, in which stimuli are filtered according to the search goal and varied degrees of processing response occur. According to this idea, attention improves visual search by increasing the response to the target and excluding distractors (Verghese, 2001). An integrative, resolving approach comes from Moore and Wolfe (2001). They suggest that the mechanisms of selective attention in human visual search are neither strictly parallel nor serial. Rather, they are simultaneously both parallel and serial.

### Contingent capture and attentional control in visual search

Nonetheless, what is at least as relevant to our task at the weekly market as how we search for our friend is information about what ultimately attracts our attention during search and the role of attentional control in this process. Recall that the shifting of attention to a stimulus is known as *attentional capture* (Theeuwes, 1992). It is subject of the ongoing discussion regarding contingent capture, which will be described in the following section. It is necessary to grasp the mechanisms of attentional capture in order to understand how and when executive functions, specifically inhibition, also referred to as suppression, assist to control attention. Furthermore, we must comprehend how attentional capture operates in order to understand why the experiments described below can reveal attentional processes.

Folk et al. (1992) hypothesized that the cognitive control state, rather than the stimulus appearance, determines whether attention is captured (Folk et al., 1992). This approach is known as *contingent-capture theory,* and it states that a stimulus will only capture a person´s attention if it contains one or more features the person is looking for. Similar to the concept of a search template, Folk et al. (1992) argued that participants adopt an attentional control setting (ACS) that determines which features of a stimulus capture attention during a task. Accordingly, attention is captured by targets and cues that are consistent with ACS; Cues that do not match the ACS are ignored (Büsel et al., 2019). Yantis (1993) added to the theory that attentional control is influenced by past experiences in addition to the current cognitive state and task goals, and that salient stimuli can activate enduring tendencies of the individual and attentional capture when no ACS is present.

The latter aspect is also in line with the stimulus-driven selection approach of Theeuwes (2010), which postulates that saliency computations occur automatically and independently of the task within a spatially constrained attentional window. Within these windows, attention is drawn to the location with the highest contrast signal. The stimulus-driven hypothesis emphasizes the spatial component of inhibition on attentional capture, suggesting that even in the presence of highly salient stimuli, attentional capture can be influenced both reactively and proactively. Nevertheless, it is not definitively clear whether this is actually spatial or yet feature-based. With their *theory of selection history-based singleton suppression*, Gaspelin et al. (2015) focus on control mechanisms for inhibiting attentional capture. They argue against the spatial aspect and underline the possibility of proactive reinforcement of feature expressions using control signals.

Luck et al. (2021) lately attempted to synthesize these theories into a summary model. It posits that visual input is processed into three feature maps, which are subsequently reassembled into a priority map to provide attentional control states**.** There is agreement that, in the absence of specific ACSs, salient stimuli generate an *attend-to-me-signal* that automatically captures attention (Sawaki & Luck, 2010). Nevertheless, shifting attention to these stimuli can be prevented by inhibitory mechanisms which are based on attentional control. The extent to which proactive suppression of certain features occurs and whether both implicit and explicit learning play a role in signal suppression are still unclear (Luck et al., 2021).

As established indices of visual attention deployment, event-related potentials (ERP) permit the elicitation of specific and well-defined mechanisms of attention (Sawaki & Luck, 2010). The N2-posterior-contralateral (N2pc) component is a specific visual ERP associated with spatial attentional deployment (Woodman & Luck, 1999), which is visible as an enhanced negativity contralateral than ipsilateral to the attention-capturing object (Eimer, 1996). It so reflects attentional capture in the presence of target stimuli or target stimulus-like distractors (Hopf, 2000, 2004) and can be observed 150-300 ms after stimulus onset (Sawaki et al., 2012).

## Suppression

An inhibitory mechanism to prevent automatic attentional capture to follow behavioral goals, for instance, during a visual search task, is suppression. As stated previously, inhibition is one of the three main executive functions of cognitive control. Suppression, as an aspect of it, is a multifaceted phenomenon of human experience. For example, we utilize suppression to detach ourselves from unpleasant memories and to avoid overindulging in sweets. However, suppression also plays a function in distinct processing processes within attentional capture. Thus, it is conceivable that, in addition to the goal-directed search for goal-determining features, top-down attentional suppression may also been used as a strategy depending on current task goals (Forstinger et al., 2022). Suppression refers here to the ability to actively inhibit bottom-up processing that is automatically evoked by particularly dominant stimuli in visual search. The purpose of suppression is to inhibit interference from distractors during task processing. Top-down attentional control restricts the use of attentional resources for these stimuli and directs them to relevant stimuli.

Distractor suppression is directly reflected by an electrophysiological measure labelled distractor positivity ($P_D$; Hickey et al., 2009; Kiss et al., 2012; Sawaki et al., 2012; Sawaki & Luck, 2010, 2011). Corresponding to the position of stimulus to be suppressed, this ERP manifests as a higher positive voltage contralateral compared to ipsilateral (Sawaki & Luck, 2012). Depending on the task, it appears 100-400 ms after stimulus onset (Drisdelle & Eimer, 2021).

Kerzel and Burra (2020) lately questioned the interpretation of PD components as an electrophysiological sign for the active suppression of saliency signals during visual search. Contradiction was caused by the observation of contralateral negativity in the results of Kerzel and Burra (2020) following PD evoked by lateral distractors. Because contralateral negativity is regarded an N2pc component and hence an electrophysiological cue to attentional capture, this observation constituted a contradiction to successful suppression. Kerzel and Burra (2020) proposed the alternative hypothesis of *lateral-first serial scanning*, wherein the alleged PD was in fact an N2pc that occurs when a lateral context object is selected.

Drisdelle and Eimer (2021) examined this issue and hypothesized these supposed

N2pcs should not be elicited, when a task requires attention to targets consistently presented along the vertical meridian. In such a task, there would be no need for participants to focus their attention on the lateral objects. Although $P_D$ components were also found by Drisdelle and Eimer (2021) on singleton distractors of negativity contralateral to the color singleton, the authors interpret these as a second $P_D$ triggered by non-salient distractors on the opposite side and present the hypothesis of sequential inhibition in opposition to lateral-first serial scanning, which may also reconcile previous contradictory results and support the notion of $P_D$ as an event-related potential for active suppression.

Sawaki and Luck (2010) investigated suppression as one of the mechanisms of visual search. They investigated attentional capture of target stimuli and suppression of distractors during task processing in a visual search task in order to examine the long-standing debate between the bottom-up saliency hypothesis and the contingent involuntary orienting hypothesis. They utilized four slightly different experimental conditions for this objective. In all experiments, participants were supposed to press a key in response to the brief presentation of a certain predefined target letter among other letters. In addition to trials with the target, there were also trials with color singletons (salient distractor condition; a nontarget letter presented in a unique color), which, according to the bottom-up saliency hypothesis, can be suppressed as they were irrelevant (Barrett et al., 2004; Fukuda & Vogel, 2009; Lavie & De Fockert, 2005; Vogel et al., 2005). In contrast, neurophysiological studies have also demonstrated that distractors with task-relevant features can also capture attention (Eimer et al., 2009; Eimer & Kiss, 2008), consistent with the contingent involuntary orienting hypothesis. Consequently, target-similar distractors were also employed in the experiment (target-similar condition; same letter as target but different size). Interestingly, Sawaki and Luck (2010) found electrophysiological evidence for the suppression of salient distractors via $P_D$ and attentional capture of target-similar distractors via N2pc. To determine whether Yoga practice improves the inhibition function und thus suppression of visual distractors, we replicated Experiment 4 by Sawaki and Luck (2010).

We chose this experiment for the following reasons: First, Sawaki and Luck (2010) separate the different categories so that only target, target-similar distractor, or salient distractor are present in a target display. Thus, it is clear which ERP is currently visible, since N2pc and $P_D$ components have similar topographies. Consequently, it is possible to comprehend which stimuli elicit which ERPs. Moreover, target stimuli in this experiment were not singletons of any dimension, as Bacon and Egeth (1994) demonstrated that otherwise a singleton detection mode can be employed. For instance, if the target letter was an

*A* among a set of *B*s, responses would be based on discontinuities in feature distribution rather than specific target features. However, when, as in the present experiment, an *A* is presented among heterogeneous other letters, task performance cannot be improved by an attentional set that emphasizes singletons since unique letter identity is no longer a distinguishing feature. Furthermore, if target stimuli were also singletons, no conclusions could be derived regarding the automatic capture of attention by irrelevant singletons. Target stimuli and salient distractors would share the property of being a singleton, and attention would no longer be captured independently of target stimulus properties. The salient distractor condition includes a color singleton since it is expected that color singletons, because of their saliency, capture attention from bottom-up, regardless of the target-defining features (e.g., Theeuwes, 1992).

We chose Experiment 4 to exclude influences of colors and thus of memory. In contrast to Experiments 1-3 of the original paper by Sawaki and Luck (2010), in Experiment 4 the color of eight letter stimuli in the target stimulus display was determined randomly with equal probability from the two available colors red and green on each trial. Therefore, the target color was unpredictable. This ruled out the possibility that participants might have had an incentive to focus on one color in order to solve the task, as they ignored the irrelevant singleton not because it was irrelevant, but because it was not presented in the target color.

We wanted to know whether improving attentional control through Yoga practice leads to an improvement in top-down suppression and, consequently, a greater increase in mean $P_D$ amplitudes for salient distractors in the intervention group compared to a waitlisted control group (with pretest values as a baseline). If Hatha Yoga influences the inhibition function of attention, we additionally expected less attentional capture by target-similar distractors, indicated by a lower mean N2pc amplitude. Furthermore, if Hatha Yoga practice influences the inhibition function of attention, we expected greater reduction of false alarms (that is, responses to distractors) in the intervention group compared to the control group from pre- to posttest measurements due to the increased inhibition of salient and target-similar distractors, resulting in a greater proportion of correct responses (as non-responses are counted as correct in those conditions).

## Switching

As we already know, another core function of attentional control is shifting, also referred to as the switching function. Likewise, the switching function has numerous expressions in our daily lives. For instance, it may be required to switch between perceptual modalities. Imagine taking the bus to the market. To ensure that you get off at the right stop, you will closely monitor the display of stop names and search for the destination´s name.

However, if a vocal announcement is made, you will attempt to gather information from it as well and listen carefully to determine if the name that is important to you is mentioned; therefore, you must quickly shift your attention from visual to auditory input. However, this approach can also be used in a constant modality, such as when searching for more than one target-relevant feature. Imagine that you cannot recall exactly if the blouse your friend is wearing at the market is blue or red, but you are certain that it is one of the two colors. There is evidence that you cannot search for both colors simultaneously, but that switching back and forth between the corresponding ACSs is required to optimally solve the task (Büsel et al., 2019). As a reminder: ACSs are proactively established as a form of attentional control in the within the setting of contingent capture and correspond to the two possible blouse colors in the preceding example. During visual search, the ACSs are responsible for the aforementioned top-down directing of attention to task-relevant features.

These switching processes depend on attentional control and are associated with costs (Büsel et al., 2019). Monsell (2003) discovered that response times (RT) were longer for trial-by-trial task switches compared to repetitions (in the following labelled switching costs; SC). In addition, the error rate was frequently elevated after a task switch. SCs in RTs during a visual search task can be calculated by subtracting the RTs following trial-by-trial target-color repetitions from RTs following trial-by-trial target-color switches. However, there may also appear SCs in the accuracy of the processing of the tasks. To evaluate this, hit rates (that is, the rate of correct answers based on all trials) in switch trials can be subtracted from hit rates in repetition trials.

An additional cost component in processing visual search tasks is searching for multiple properties at the same time. Irons et al. (2012) proposed that multiple ACSs can simultaneously be active in WM for different colors. Grubert and Eimer (2016) tested this with an N2pc study and concluded that ACSs can contain more than one feature within the specific dimension.

Multiple templates in WM have been a topic of discussion for some time. Previous research has suggested that representations stored in WM provide the inputs responsible for attentional selection of task-relevant stimuli (Desimone & Duncan, 1995; Duncan & Humphreys, 1989). However, the capacity of the WM for attentional templates is limited (Schneider & Shiffrin, 1977). Although previous research has indicated that WM can hold approximately three to four items (Cowan, 2001; Luck & Vogel, 1997), only one template can be active at any given time (for a review, see Olivers et al., 2011).

There is evidence that ACSs for multiple properties of a dimension (such as multiple colors simultaneously) are less efficient than sets for a single property (Dombrowe et al., 2011; Menneer et al., 2009; Wolfe et al., 1990). It had already been shown by Los (1996) that participants responded more slowly to target stimuli when they had to look for two potential target colors rather than one. This was labelled *mixing costs* (MC).

A way to investigate MCs in visual search tasks is to compare blocks containing just one possible target color to blocks containing two possible target colors with equal probability. From this, MCs in RTs can be calculated by subtracting RTs in single-color blocks from RTs to trial-by-trial target-color repetitions in dual-color blocks. Moreover, costs can also be examined in hit rates: Therefore, hit rates in dual-color blocks can be subtracted from hit rates in repetition trials in single-color blocks. Büsel et al. (2019) studied the application of ACSs in a dual-color visual search task. This paradigm permits simultaneous examination of both of the described costs associated with attentional shifts. In this experiment, it is also conceivable to investigate spatial validity effects and intertrial priming of cues in dual-color blocks, but this will be reported by Szaszkó et al. (currently in preparation), thus it is not described in detail here.

Let us recall briefly what occurs in Yoga: Alternating between the monitoring of the hand and the spine and the monitoring of the breath while listening to the yoga instructor's instructions. We questioned if Hatha Yoga practice, by enhancing attentional control and practicing switches on a physical level, leads to faster and more error-free switching between ACSs in an IG compared to a CG as a result of far transfer.

If Hatha Yoga has an effect on switching between two distinct ACSs, we expect members of the IG to have a greater reduction of SCs, indicated by a decrease of RTs and increase of hit rates for trial-by-trial switches than repetitions of a task from pre- to posttest measurements than members of the CG in a dual-color visual search task. Additionally, if Hatha Yoga has an effect on switching between two distinct ACSs, we expect members of the IG to have a greater reduction of MCs than members of the CG from pre- to posttest measurements, indicated by reduction of RTs and increase of hit rates for trial-by-trial target-color repetitions in single-color blocks compared to trial-by-trial target-color repetitions in dual-color blocks (cf. Büsel et al., 2019).

# Method

In the following, passages that were developed and formulated together with Mira Maiworm are formally marked as quotations from the master's thesis of Mira Maiworm (2022). This is since this master's thesis was completed and submitted after Mira Maiworm's. However, this is only a formality, and they appropriately are in fact developed in equal parts by Mira Maiworm and me.

## Participants

A power analysis with G*Power (Erdfelder et al., 1996) yielded a sample size of 102 participants, with *d* = 0.5, 80 % power, and an alpha error probability of .05, based on a one-tailed *t*-test. However, it should be noted that due to the diversity and heterogeneity of the applied methodology (including [electroencephalography;] EEG, behavioral, and questionnaire measures), the here used single estimated power value only provides us with power information about the worst case, namely questionnaires (pretest and posttest). Behavioral experiments using thousands of trials per participant tend to have much higher power due to reliable within-subject effects. This is especially the case for EEG recorded data, where the number of trials per cell often exceeds 100. Thus, power in our behavioral experiments (and even in the saliva measures with 30 measurements for each participant) was significantly higher than in the case of the questionnaires, even after the unexpectedly high rate of data that had to be excluded from analyses, which will be discussed in detail later (see section "Limitations", p. [41]). The expected effect size was based on previous studies on the effects of Yoga and attention (Gothe et al., 2013; Oken et al., 2006). Accounting for an estimated dropout rate of 20 %, we aimed to recruit 122 participants through the study platform Laboratory Administration for Behavioral Sciences of the University of Vienna (UoV), the Vienna CogSciHub: Study Participant Platform, and social media advertisement. 105 [*sic*] participants (83 female; $M_{\text{Age}}$ = 25.03 years; $SD_{\text{Age}}$ = 4.18 years; range 18-40 years) completed both pretest sessions and were still part of the study as the intervention started. Before participation, subjects had to perform a shortened

> online version of the Diagnostic Interview for Mental Disorders (Mini-DIPS; Margraf et al., 2017), a screening instrument for mental disorders with a high reliability of Cronbach's alpha between .84 and .90 for the different disorders (Margraf, 1994). Besides current mental disorders other exclusion criteria were age under 18 or over 40 years, German level under C1, previous Yoga practice exceeding twice a month in the past year, uncorrected visual or hearing impairment, skull fractures or concussions within the past six weeks, and non-provision of a recovery or vaccination Covid-19 certificate. A one-time sample characterization, assessing age and gender[1], was obtained at baseline using the Patient Health Questionnaire (PHQ-D; Gräfe et al., 2004). All participants signed written informed consent and received detailed debriefing. Ethical approval of the Ethics Committee of the UoV was obtained. (Maiworm, 2022, pp. 14-15)

## Study Design

Figure 1 shows our study design. Participants were divided into two equally sized cohorts. Each cohort followed the same procedure except start dates (early vs. late start date). After undergoing the screening, participants completed the pretests in two appointments.

> In the first pretest session, participants signed informed consent and performed an experimental task aiming at assessing switching between different ACSs. In the second pretest session, participants were trained in saliva sample collection (SSC)[2], received equipment for SSC, and performed two experimental tasks, with the first one aiming at

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[1] Next to age and gender, other sample characteristics such as educational level and financial income were obtained. However, since they are not of relevance to the object of the current paper, they are not further described here.

[2] SSC and questionnaires (except screening) were conducted to investigate the relationship of Yoga practice, stress, anxiety and mindfulness and will be reported by Maiworm (currently in preparation).

> assessing their inhibition function and the second one aiming at assessing their ability to switch between different modalities[3]. (Maiworm, 2022, p. 15)

In both, the results were measured via EEG. Experiments were conducted in a dimly lit room. Following the completion of the experiments, participants received an email with their randomized group assignment: Intervention group (IG; *n* = 54) or control group (CG; *n* = 51).

> SSC and performance of online questionnaires, assessing stress, anxiety, and TM, took place in the week after the second pretest session. The IG then received an eight-week Hatha Yoga course, while the CG did not receive an intervention during this time period but after the IG finished the intervention, thereby serving as a wait list control group. The two posttest sessions differed from the pretest sessions in two ways: First, participants received the SSC equipment already in the first session. Secondly, questionnaires, including a post-monitoring intervention questionnaire for the IG, were performed within three days after the end of the intervention. SSC took place one and a half weeks after the end of the intervention. This was done in order to ensure that the distance between the intervention and the pretest/posttest saliva measurements and questionnaires was constant. While the study ended for the IG after the second posttest session, the CG then received the Hatha Yoga course, followed by two posttest sessions with the same procedure as the previous posttests. Study design is illustrated in Figure [1]. Participants received the following financial compensation: Regardless of their group belonging (IG or CG), all participants received an eight-week Hatha Yoga course free of charge. Further, they received 30 EUR for successful completion of pre- and posttests, respectively, if all other requirements were met (course attendance at least three times a week for the IG, completion of questionnaires and saliva testing for both groups). If participants attended

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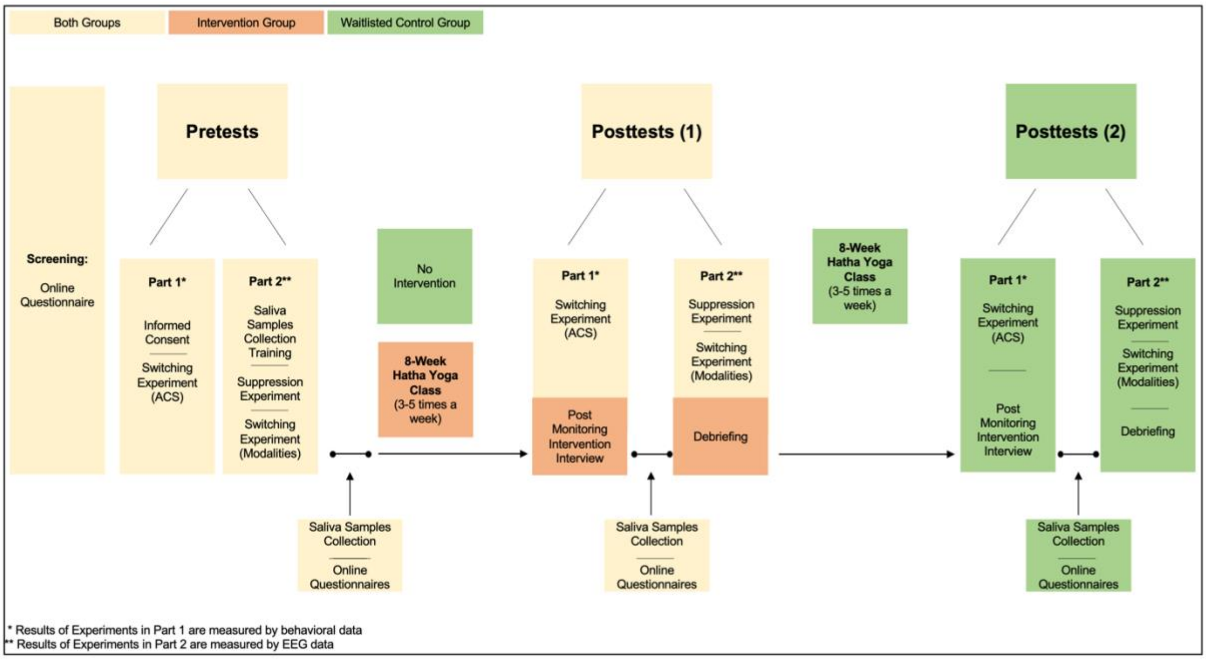
[3] Will be reported by Szaszkó et al. (currently in preparation).

four Yoga sessions a week on average, they received a bonus of 20 EUR. Accordingly, participants of the IG could receive a financial compensation up to 80 EUR and participants of the CG could receive a financial compensation up to 110 EUR, since they received additional 30 EUR for completion of the second posttests. (Maiworm, 2022, p. 16)

**Figure 1**

*Study Design*



*Note*. This figure illustrates the study design dependent on group membership. The intervention group (IG) received the intervention after the pretests, the waiting control group (CG) received no intervention during this period. After posttests 1, the study ended for the IG. The CG then received the intervention, followed by posttests 2. (Maiworm, 2022, p. 16)

## Intervention

The eight-week Hatha Yoga course was guided by trained instructors at a yoga studio ($M_{\text{Job Experience}}$ = 4.00 years; $SD_{\text{Job Experience}}$ = 1.15 years; range 3-5 years of job experience), with each session being instructed by one of four female instructors ($N = 4$). To control for biases through different instructions and styles, instructors were briefed together by the experimenters and received a strict program to be followed. Each week, a different focus was set in all the yoga sessions for that week. The different focuses per week as well as exemplary asanas (yoga postures) can be seen in Table [1]. (Maiworm, 2022, p. 17)

**Table 1**

*Focus of Yoga Sessions per Week and Exemplary Asanas*

| Week | Focus | Exemplary Asanas |
|---|---|---|
| 1 | Sun salutation, breathing exercises | Downward Facing Dog, Cobra Pose, Sprinter Pose |
| 2 | Standing positions | Warrior I and II, Triangle Pose, Chair Pose |
| 3 | Forward Bends | Different variations of Forward Bends, Pigeon Pose, Butterfly Pose |
| 4 | Twists | Waists Turn, Crocodile Pose, twisted Triangle Pose |
| 5 | Backbends | Shoulder Brigde, Locust Pose, Bow Pose |
| 6 | Sitting poses | Different variations of Lotus positions, Boat Pose, Child Pose |
| 7 | Balance | Tree Pose, Warrior III, Crow Pose, Half Moon Pose |

| | | |
|---|---|---|
| 8 | Combining focuses 1-7 | Combinations of the previous exemplary asanas |

*Note.* A distinct focus was established for each of the eight weeks of the Hatha Yoga intervention, determining the asanas that week. All instructors were required to follow this focus while they guided their classes.

Each 60 min session consisted of 5-10 min warm-up exercises, 40-50 min *asanas*, and 5-10 min *savasana* (relaxing while lying flat on the back). The Essential Properties of Yoga Questionnaire (EPQY; Groessl et al., 2015), consisting of 62 items and with an acceptable to good reliability of Cronbach's alpha between .70 and .90 for different subscales (Park et al., 2018), was used to characterize the Yoga intervention. All items are introduced with "How much the instructor mention or include…" and rated from 1 (not at all) to 5 (a very large amount), with higher scores indicating a higher level of mentioning/inclusion of the regarding Yoga element. Since it is impractical to expect all fourteen different components to be addressed in a Yoga intervention, and different Yoga styles vary on the focus and inclusion of components (Park et al., 2018), we decided to include the following five subscales in our analyses: Acceptance/compassion (e.g., "... acceptance of things as they are?"), breathwork (e.g., "... linking breathing with movement?"), physicality (e.g., "... physical balance?"), body awareness (e.g., "...asking students to concentrate on bodily sensations [such as tightness, softness, and muscle awareness]?"), and meditation/mindfulness (e.g., "...mindfulness [non-judgmental awareness of one's thoughts, feelings, or movements]?"). While we assessed acceptance/compassion, and meditation/mindfulness as classic components of MBIs in general (Kabat-Zinn, 2015; Park et al., 2021), we also assessed breathwork, physicality, and body awareness, since they are more specific for Hatha Yoga (Shapiro et al., 1998). While Table [2] gives a descriptive overview of the EPYQ outcomes for each included subscale, Figure [2] presents a graphic

> illustration of the proportion of elements included in our Hatha Yoga intervention. Participants were instructed to attend at least three and maximum five Yoga sessions per week. They had to sign an attendance list at the Yoga studio before each attended Yoga session. Each week, three to four early sessions (8 am), and five late sessions (5 or 7 pm) were offered. The Yoga course feasibility was assessed by each participant at the end of the intervention using a specially constructed post-monitoring interview for this purpose. However, since the analysis of the post-monitoring interview is conducted in a time-consuming qualitative manner by a collaborative group of the study, results of the post-monitoring interview have not yet been finalized. Therefore, they will be reported in the paper by of Szaszkó et al. (currently in progess [*sic*]). (Maiworm, 2022, pp. 17-18)

**Table 2**

*Essential Properties of Yoga Questionnaire Outcomes divided by Subscales*

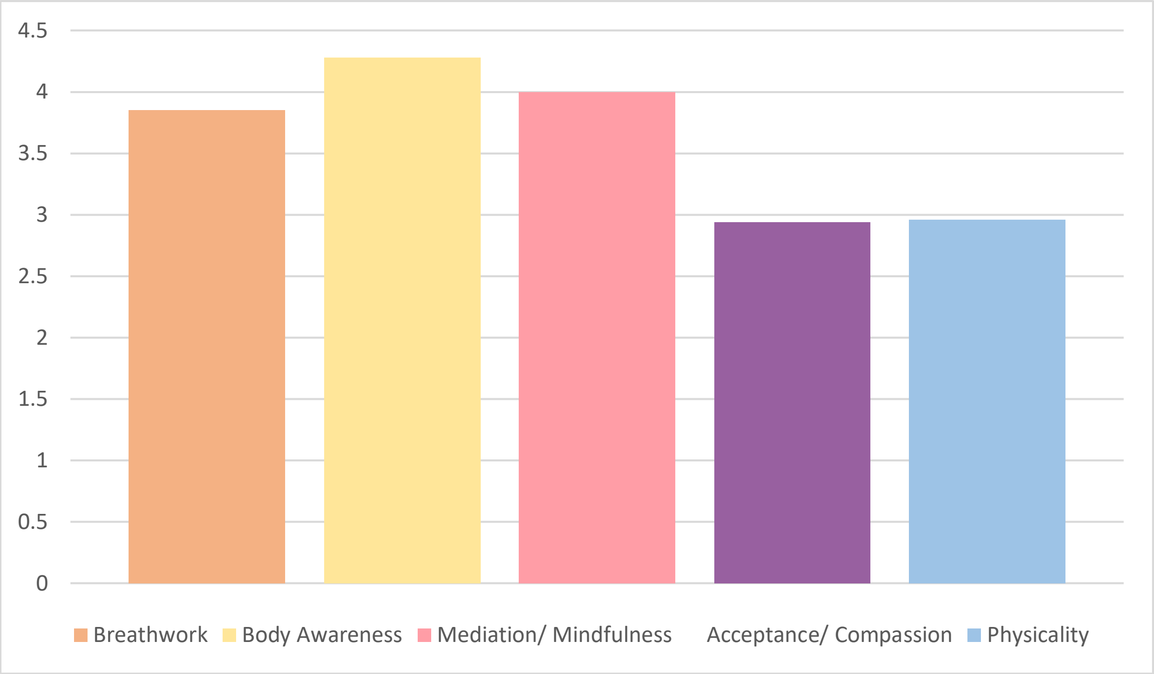
| Subscale | *M* [CI] | *SD* |
|---|---|---|
| Acceptance/Compassion | 3.85 [1.85, 4.15] | 0.72 |
| Breathwork | 4.28 [3.03, 4.97] | 0.61 |
| Physicality | 2.94 [1.17, 2.83] | 0.52 |
| Body Awareness | 4.00 [3.25, 4.75] | 0.47 |
| Meditation and Mindfulness | 2.96 [1.00, 1.88] | 0.95 |

*Note. M* = Mean, CI = 95 % confidence intervals, *SD* = Standard deviation. *N* = 4. We calculated means and standard deviations of the five included subscales (acceptance/compassion, breathwork, physicality, body awareness, mindfulness/meditation) to compare the amount to which components were included. Values between 1 and 2 indicated a small amount of inclusion of this component, values between 2 and 3 a small to moderate inclusion amount, values between 3 and 4 a moderate

> to large inclusion amount, and values between 4 and 5 a large inclusion amount (e.g., Park et al., 2018). (Maiworm, 2022, p. 17)

**Figure 2**

*Proportion of Elements included in the Hatha Yoga Intervention*



## Suppression Experiment

### *Participants*

Only datasets from participants taking part in pre- and posttests were analyzed, resulting in 71 datasets. After excluding two subjects due to an insufficient rate of correct answers based on the result of a generalized extreme studentized deviate test sensitive for multiple outliers (we tested for three outliers; Rosner, 1983), data from 69 participants were analyzed (60 female; $M_{\text{Age}}$ = 25.06 years; $SD_{\text{Age}}$ = 4.54 years; range 19-40 years).

### *Apparatus*

Stimuli were displayed on a 19’’ Cathode Ray Tube (CRT) Monitor (Sony Multiscan, viewable size: 36.4 × 27.3 cm) with an aspect ratio of 4:3 and a resolution of 1,024 × 768 pixels at 100 Hz vertical refresh rate. A chin rest was used to maintain a constant viewing distance of 57 cm between the participants and the CRT monitor. Participants responded via a conventional QWERTZ-keybord. Presentation of stimuli and collection of responses was managed by OpenSesame, Version 3.10 (Mathôt et al., 2012).

### *Stimuli*

Stimuli were presented on a black background (CIE L*a*b*, 7.8/22.7/−27.4). The display permanently contained a white (104.1/15.6/−52.9) fixation cross (0.4° wide, 0.4° tall) at the center of the display and two white rectangles (18.5° wide, 3.5° tall), which were centered 4.5° above and below the fixation cross. Eight uppercase letters appeared in each stimulus array. They were distributed equally in the upper and the lower visual field (four each). The set for letter selection contained *A*, *H*, *I*, *M*, *O*, *T*, *U*, *X*, and *Y*. These were chosen based on their symmetrical features and so did not exhibit any laterals in the ERPs. In each stimulus array, two small (1.6° wide 2.0° tall) and two large letters (2.0° wide 2.5° tall) were positioned within each upper and lower rectangle. The position of the letters was 5° or 8° to the left or right of the vertical midline and 4.5° above or below the horizontal midline. There was a random variation of letter identity and letter size across trials, except that the number of large and small letters within each rectangle was equal. The items were either red (57.0/-64.6/51.7) or green (57.4/75.0/60.6). Stimuli were shown for 200 ms, and the interstimulus interval varied randomly between 800 and 900 ms.

### *Procedure*

For each block, respectively, a letter of a certain identity and size (large or small) was defined as the target from the nine letters (e.g., a small *H*). Each letter just mentioned occurred two times in each size, resulting in a total of 36 blocks for nine letters with two sizes each. The participants were instructed to maintain fixation on the fixation cross and to respond when they detected the target letter by pushing the “down arrow” key. Speed and accuracy were equally stressed. Trials in which response times were shorter than 100 ms or longer than 800 ms were excluded from all analyses (1.6 % and 1.1 % of correct target trials, respectively). The experiment lasted approximately 45 minutes with breaks of which length could be determined by participants themselves.

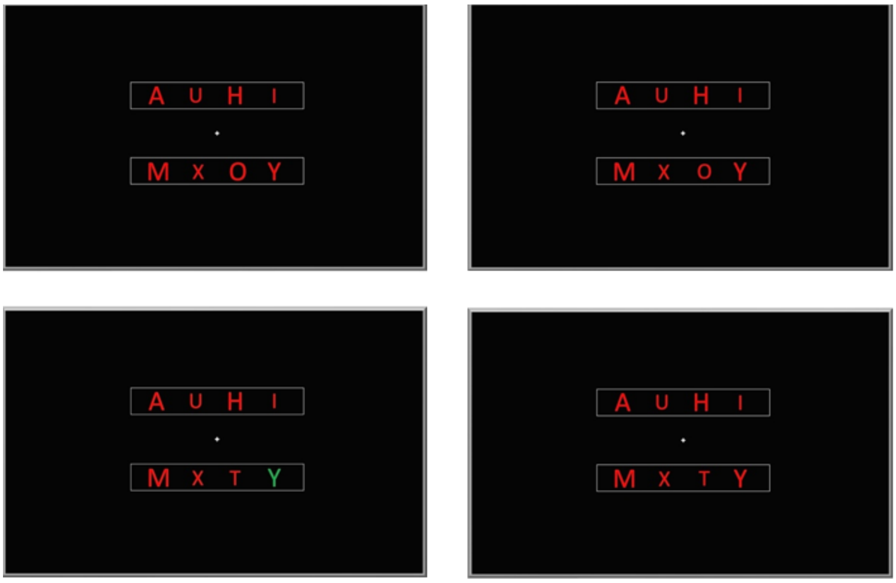
### *Design*

The experiment was composed of four different conditions. The target condition consisted of trials that included a target stimulus (576 trials, approximately 28.6 %). The target-similar condition contained trials that involved the same letter as the target, but in a different size (the target-similar distractor; 576 trials, approximately 28.6 %). In the salient distractor condition (576 trials, approximately 28.6 %), the salient distractor was a color singleton (thus had a different color compared to all other stimuli in the target display) and differed in letter identity from the target. This implies that the salient distractor, unlike the target-similar distractor, could be categorized as irrelevant (as participants could always suppress a color different from all other items in the target display known to be task-irrelevant). The control condition consisted of trials that did not meet any of the previously mentioned conditions (288 trials, approximately 14.3 %). In half of the trial blocks, all the items were red, except the salient distractor, which was green. The colors switched from trial to trial. The letter identity and the letter size at each stimulus location were varied randomly across trials, with the constraint that the number of large and small letters within each rectangle was equal. Each participant performed 72 practice trials, followed by 36 blocks of 56 trials during which ERPs were recorded.

The color of eight letter stimuli in the target stimulus display in Experiment 4 was determined randomly from the two possible colors red and green with equal probability on each trial. Figure 3 shows exemplary trials for all conditions.

**Figure 3**

*Suppression Experiment*



*Note*. In this figure, the four conditions of the suppression experiment are presented. In this example, participants had to look for a big *O* and press the down arrow when the target was present. The first condition (upper left corner) includes a target stimulus, hence, a big *O* is presented. In the second condition (upper right corner), a target-similar distractor is

> shown, as to be seen by presentation of a small *o*. In the third condition (lower left corner), a salient distractor in a different color from all other stimuli is presented, here a green *Y* among seven red letters. The fourth condition (lower right corner) served as a control condition, including trials that did not meet criteria of condition 1 to 3. (Maiworm, 2022, p. 22)

### ***Data Analysis***

Due to short response times (trials under 100 ms), 0.46 % of all target trials were excluded from further analysis. Only correct trials were analyzed. The free software environment "R" (Version 3.6.3; R Core Team, 2018) and the free software "JASP" were used to analyze the data (Version 0.16; JASP Team, 2021). We used a significance level of $p < .05$ to determine if our results differed significantly from those predicted if the null hypotheses were correct.

To examine the effect of the intervention on suppression on a behavioral level, we used participants´ mean response times (RTs), false alarm rates (FAs; that is, responses in conditions when there was no target) and accuracy rates (ARs; that is, the rate of correct answers based on all trials: Combined hit rates from target condition and non-responses from target-similar condition, salient distractor condition and control condition). To assess if there was an effect of the intervention on RTs, we conducted a two-way (2 x 2) mixed Analyses of Variance (ANOVA), with the repeated within-subject factor “measurement” (pretest/posttest), between-subjects factor “group” (IG/CG) and the dependent variable “RTs”. To assess the effect of the intervention on FAs and ARs, we conducted two three-way (2 x 2 x 3) mixed ANOVAs, with the repeated within-subject factor “measurement” (pretest/posttest), the within-subject factor “condition” (salient distractor/target-similar/control) and between-subjects factor "group" (IG/CG) and the dependent variables "FAs" and “ARs”. We used partial eta squared ($\eta_p^2$) to determine the effect sizes with .01 indicating a small, .06 indicating a medium, and .14 indicating a large effect (Cohen, 1988).

In line with our hypotheses, we conducted planned comparisons using one-sided $t$-tests for independent samples. We tested if there were significantly less FAs and significantly higher ARs from pre- to posttest measurements in the IG compared to the CG. Cohens´s $d$ was used to determine the size of effects, with < 0.50 indicating a small, between 0.50 and

0.80 indicating a medium, and > 0.80 indicating a large effect (Cohen, 1988).
The ERP results will be reported by Szaszkó et al. (currently in preparation).

## Switching Experiment

Due to the fact that we replicated this experiment as described by Büsel et al. (2019), there is overlap in the methodological description. Some terminology is not interchangeable for comprehending the experimental setup. It is explicitly stated that the experiment described here is a replication of Büsel et al. (2019).

### *Participants*

Only datasets from participants taking part in pre- and posttests were analyzed, resulting in 74 datasets. The result of a generalized extreme studentized deviate test sensitive for multiple outliers (we tested for three outliers; Rosner, 1983) did not require exclusion of data, hence, all 74 participants were analyzed (64 female; $M_{\text{Age}}$ = 24.95 years; $SD_{\text{Age}}$ 4.48 years; range 18-40 years).

### *Apparatus*

A 24.5” G2590PX AOC Gaming LCD monitor (visible part of the display: 54.4 cm x 30.3 cm) monitor with refresh rate of 100 Hz was used. The participants responded via a conventional QWERTZ-keybord with a viewing distance of 57 cm. To prevent the participants to be distracted by any backround noise, they were asked to wear hearing protection. Additionally, they were told to use a chin-forehead-rest to maintain a consistent viewing distance. Presentation of stimuli and collection of responses was managed by OpenSesame, Version 3.10 (Mathôt et al., 2012).

### *Stimuli*

During trials, a grey fixation cross (0.6° x 0.6°) first appeared against a black fixation background (CIE L*a*b*, 7.8/22.7/−27.4). In addition, four gray circles (outline width: 0.1°; radius: 1.2°) with a 2.7° eccentricity were displayed as placeholders at the corners of an imagined square in the center of the screen. In the following cueing display and target displays, outlines of placeholders increased to 0.3°. In the cueing display, one of the rings took on the target color (or in dual-color blocks one of the target colors) (matching cue), while the other three remained gray, or it took on another color, namely blue (nonmatching cue), so it was a color singleton in any case. In dual-color as well as single-color blocks, cues were equally likely to be matching or non-matching, leading to 50 % matching and 50 % nonmatching cues. After an interstimulus interval, the target display appeared, in which only color rings were present so there were no color singletons, but only one of them got a target color. Two of three remaining rings became yellow, and the fourth ring became either magenta or cyan with equal probability to prevent singleton detection mode and to force target color search. Colors were equally bright (L = 70 in L*ab color space) red (CIE coordinates: a = .65, b = .34), green (.28, .59), blue (.14, .07), cyan (.21, .33), magenta (.33, .17), yellow (.43, .50), and gray (.31, .33). In addition, during the target display, a white *T* (0.5° x 0.4°) tilted 90° to the left or right appeared in all circles. In the dual-color block, the color of the target stimulus changed in run n+1 compared to run n with a 50 % probability, so equal numbers of trials with target color repetitions and target color changes were obtained.

### ***Procedure***

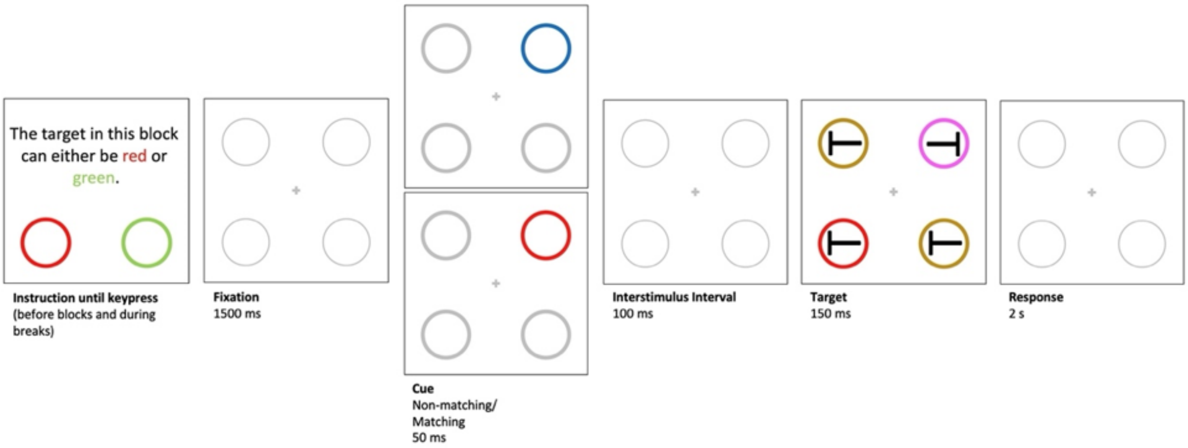
Figure 4 shows one exemplary trial. Participants were instructed to push a key to indicate if the *T* in the target color circle was left- or right-tilted (key *y* for left- and *m* for right-tilted). Each trial included a fixation display (1,500 ms), a following cueing display (50 ms), a cue-target interval equal to the fixation display (100 ms), a target display (150 ms), and a response display identical to the fixation display (for 2 s). Participants were instructed to respond as quickly and accurately as possible. They also received written feedback on their performance (500 ms each) by displaying "Falsch" (“Wrong”) on the screen for incorrect responses, and “Schneller antworten!” ("Respond faster!”) for response times longer than 1200 ms. Response times were measured. Participants had the opportunity to take self-paced breaks every 120 trials.

### ***Design***

The experiment included single-color and dual-color conditions, each presented in different blocks (A-B-A-B or B-A-B-A, balanced across subjects). All remaining conditions were pseudo- randomized within blocks. While in single-color blocks target stimuli appear exclusively in the color defined at the beginning of the block, in dual-color blocks there were two target colors, red and green, one of which always appeared in the target stimulus display. In dual-color blocks, the color of the target stimulus changed in trial n+1 compared to trial n with a 50 % probability, so equal numbers of trials with target color repetitions and target color switches were obtained. A total of four blocks of 240 experimental trials each with varying condition blocks and 24 practice trials each were conducted, resulting in 960 data-collection trials in total and an approximate duration of 60 min including breaks. In addition, cue- and target positions were uncorrelated to avoid that the cue facilitated target detection by being a spatial and not feature based hint, leading to 25 % spatially valid and 75 % spatially invalid trials.

**Figure 4**

*Switching between Attentional Control Settings Experiment*



*Note.* This figure illustrates an exemplary trial of the experiment aiming to assess switching between different Attentional Control Sets. In the first display, participants got informed about the possible target color(s). These could either be red, green or both, as it is the case in this trial. After a fixation display, a cueing display was shown with either a non-matching cue, hence, a cue in a different color from the target (here blue), or a matching cue of the same color as the target (here red). Additionally, the cue could appear under valid conditions, hence, at the same position as the subsequent target, or under invalid conditions, hence, at a different position as the subsequent target, as shown in this exemplary trial. After an interstimulus interval, the target display was presented (here, the target is presented in the lower left corner of the display). Finally, a response display was presented, during which participants had to indicate as quick and accurate as possible in which direction the *T* within the target was directed (here left). (Maiworm, 2022, p. 26)

### *Data Analysis*

For data analysis, practice trials as well as trials with RTs deviating more than 2.5 *SD*s from individuals´ means were excluded (2.11 % of all trials). We excluded trials with cues matching the location of the target of the prior trial (9.85 % of all trials) to eliminate location priming effects (e.g., Casco & Campana, 2009). Only correct trials (93.59 % of trimmed trials) were analyzed. We used participants´ RTs and hit rates to calculate our dependent variables. We calculated SCs and MCs based on both dependent variables used. For RTs, SCs (for dual-color blocks only) are mean correct RTs following trial-by-trial target-color switches (switch trials) minus mean correct RTs following trial-by-trial target-color repetitions (repetition trials); for hit rates, SCs are mean hit rates in repetition trials minus mean hit rates in switch trials. Thus, positive values always indicate costs (or their increase over time), while negative values always indicate benefits (or the decrease of costs over time). MCs were calculated as follows: For RTs, as mean correct RTs to trial-by-trial target-color repetitions in dual-color blocks minus mean correct RTs in single-color-blocks; for hit rates, as mean hit rates in repetition trials in single-color blocks minus mean hit rates in dual-color blocks. Only trials from dual-color blocks in which the cues and the targets had the same color were used in this analysis (same applies to single-color blocks, as no color switches occurred in those). We did not transform hit rates as our main variables of interest, namely SCs and MCs, were normally distributed.

Data was analyzed using the free software environment “R” (Version 3.6.3; R Core Team, 2018) and the free software “JASP“ (Version 0.16; JASP Team, 2021). We chose a significance level of $p < .05$ to determine if our results differ significantly from those predicted if the null hypothesis is correct.

To assess the effects of the intervention on switching between ACSs, we conducted four two-way (2 x 2) mixed ANOVA, with the repeated within-subject factor “measurement” (pretest/posttest), between-subjects factor “group” (IG/CG) and the dependent variables “RTs” (SCs/MCs)” and “hit rates” (SCs/MCs)”. We used partial eta squared ($\eta_p^2$) to determine the effect sizes with .01 indicating a small, .06 indicating a medium, and .14 indicating a large effect (Cohen, 1988).

In line with our hypotheses, we conducted planned comparisons using one-sided *t*-tests for independent samples. We tested if there were significantly less SCs in RTs, significantly less SCs in hit rates, significantly less MCs in RTs and significantly less MCs in hit rates from pre- to posttest measurements in the IG compared to the CG. Cohens´s *d* was used to determine the size of effects, with < 0.50 indicating a small, between 0.50 and 0.80 indicating a medium, and > 0.80 indicating a large effect (Cohen, 1988).

# Results

## Suppression Experiment

### *Descriptives*

Hit rate was 75.55 %. The overall AR was 89.43 % and overall FAs were 3.91 % (10866). Participants answered in 89.14 % of trials correct (247.997). Before presenting the statistical results of the ANOVAs and the planned comparisons, we provide a descriptive overview of the FAs (as the variable of main interest for our hypotheses) in the IG and the CG in the pretest and posttest measurements in Table 3.

**Table 3**

*False Alarm Rates (%) for Salient Distractor, Target-similar Distractor and Control Condition*

| **Condition** | **Measurement** | **Group** | **FA [CI]** | ***SD*** |
|---|---|---|---|---|
| Target-similar distractor | Pretest | IG | 13.70 [11.96, 15.45] | 4.84 |
| | | CG | 12.95 [11.34, 14.56] | 4.83 |
| | Posttest | IG | 10.22 [9.20, 11.24] | 2.82 |
| | | CG | 9.43 [8.13, 10.74] | 3.92 |
| Salient distractor | Pretest | IG | 0.85 [0.15, 1.56] | 1.97 |
| | | CG | 0.75 [0.16, 1.35] | 1.78 |
| | Posttest | IG | 0.40 [0.00, 1.12] | 2.00 |
| | | CG | 0.54 [0.00, 1.32] | 2.35 |
| Control | Pretest | IG | 0.86 [0.18, 1.55] | 1.90 |
| | | CG | 0.90 [0.35, 1.45] | 1.65 |
| | Posttest | IG | 0.39 [0.00, 1.16] | 2.14 |
| | | CG | 0.80 [0.10, 1.51] | 2.11 |

*Note.* FA = False alarm rate, CI = 95 % confidence intervals, *SD* = Standard deviation, IG = Intervention group, CG = Control group. $N = 69$, $n_{IG} = 32$ and $n_{CG} = 37$.

### *Response Times*

The two-way mixed ANOVA revealed that there was no significant main effect of group on RTs, *F*(1, 67) = 0.36, *p* = .552, $\eta_p^2$ = .01, nor of timepoint on RTs, *F*(1, 67) = 3.04, *p* = .086, $\eta_p^2$ = .04. We found no significant interaction between group and timepoint, *F*(1, 67) = 0.38, *p* = .538, $\eta_p^2$ = .01

### *False Alarm Rates*

The three-way mixed ANOVA revealed that there was no significant main effect of group on FAs, *F*(1, 67) = 0.08, *p* = .776, $\eta_p^2$ < .01. We found both a significant main effect of condition on FAs, *F*(2, 134) = 325.28, *p* < .001, $\eta_p^2$ = .83, and a significant main effect of time point on FAs, *F*(1, 67) = 34.46, *p* < .001, $\eta_p^2$ = .34. Since we were mainly interested in differences between the two groups and not between the conditions in general, no post-hoc tests for the significant main effect of condition on FAs was conducted. We found neither a significant interaction between group and condition, *F*(2, 134) = 0.56, *p* = .458, $\eta_p^2$ = .01, nor a significant interaction between group and time point, *F*(1, 67) = 0.17, *p* = .679, $\eta_p^2$ < .01. There was a significant interaction between condition and time point, *F*(2, 134) = 39.70, *p* < .001, $\eta_p^2$ = .37. The interaction between group, condition, and time point was not significant, *F*(2, 134) = 0.13, *p* = .734, $\eta_p^2$ < .01. According to one-sided *t*-tests for independent samples, reduction of FAs from pre- to posttest measurements did not deviate significantly from each other in target-similar condition between CG (*M* = –3.60 %; *SD* = 4.23 %) and IG (*M* = –3.40 %; *SD* = 4.19 %), *t*(67)= –0.20; *p* = .577; *d* = –0.05, or in salient distractor condition between CG (*M* = 3.60 %; *SD* = 4.23 %) and IG (*M* = 3.4 %; *SD* = 4.19 %), *t*(67)= 0.86; *p* = .197; *d* = 0.21.

### *Accuracy Rates*

The three-way mixed ANOVA revealed that there was no significant main effect of group on ARs, *F*(1, 67) = 0.22, *p* = .638, $\eta_p^2$ < .01. We found a significant main effect of condition on ARs, *F*(3, 201) = 377.13, *p* < .001, $\eta_p^2$ = 0.85, and a significant main effect of timepoint on ARs, *F*(1, 67) = 17.76, *p* < .001, $\eta_p^2$ = .21. Since we were mainly interested in differences between the two groups and not between the conditions in general, no post-hoc tests for the significant main effect of condition on false alarms was conducted. We found no significant interaction between group and condition, *F*(3, 201) = 0.26, *p* = .857, $\eta_p^2$ < .01, nor between group and timepoint, *F*(1, 67) = 0.28, *p* = .596, $\eta_p^2$ < .01. There was a significant interaction between condition and timepoint, *F*(3, 201) = 11.84, *p* < .001, $\eta_p^2$ = .15. We found no interaction between group, condition and timepoint, *F*(3, 201) = 0.09, *p* = .967, $\eta_p^2$ < .01.

According to one-sided *t*-tests for independent samples, change in ARs did not deviate significantly from each other in the salient distractor condition between CG (*M* = 0.17 %; *SD* = 0.78 %) and IG (*M* = 0.50 %; *SD* = 2.10 %), *t*(67)= –0.86; *p* = .197; *d* = –0.21, as well as in the target-similar condition between CG (*M* = 3.60 %; *SD* = 4.23 %) and IG (*M* = 3.40 %; *SD* = 4.19 %), *t*(67)= 0.20; *p* = .577; *d* = 0.05.

## Switching Experiment

### *Descriptives*

We present a descriptive summary of the outcomes at pre- and posttest measurements for the IG and the CG in Tables 4-7 before providing the statistical findings of the ANOVAs and planned comparisons.

**Table 4**

*Mixing Costs (in ms) in Response Times*

| Measurement | Group | MC [CI] | *SD* |
|---|---|---|---|
| Pretest | IG | 27.78 [20.14, 35.41] | 21.88 |
|  | CG | 16.66 [12.02, 21.29] | 14.49 |
| Posttest | IG | 14.13 [6.50, 21.77] | 21.88 |
|  | CG | 13.54 [8.91, 18.17] | 14.49 |

*Note.* MC = Mixing Costs, CI = 95 % confidence intervals, *SD* = Standard deviation, IG = Intervention group, CG = Control group. *N* = 74, $n_{IG}$ = 34 and $n_{CG}$ = 40. Positive values in MCs represent longer RTs in dual- compared to single-color blocks.

**Table 5**

*Switching Costs (in ms) in Response Times*

| Measurement | Group | SC [CI] | *SD* |
|---|---|---|---|
| Pretest | IG | 12.67 [8.42, 16.91] | 12.17 |
| | CG | 7.40 [3.98, 10.81] | 10.69 |
| Posttest | IG | 9.92 [5.68, 14.17] | 12.17 |
| | CG | 6.15 [2.73, 9.56] | 10.68 |

*Note.* SC = Switching Costs, CI = 95 % confidence intervals, *SD* = Standard deviation, IG = Intervention group, CG = Control group. $N = 74$, $n_{IG} = 34$ and $n_{CG} = 40$. Positive values in SCs represent longer RTs in switch trials compared to repetition trials.

**Table 6**

*Mixing Costs (in %) in Hit Rates*

| Measurement | Group | MC [CI] | *SD* |
|---|---|---|---|
| Pretest | IG | 2.54 [0.71, 4.38] | 5.25 |
| | CG | 2.16 [0.88, 3.43] | 3.99 |
| Posttest | IG | 0.59 [–1.24, 2.42] | 5.25 |
| | CG | 0.58 [–0.70, 1.85] | 3.99 |

*Note.* MC = Mixing Costs, CI = 95 % confidence intervals, *SD* = Standard deviation, IG = Intervention group, CG = Control group. $N = 74$, $n_{IG} = 34$ and $n_{CG} = 40$. Positive values in MC represent higher hit rates in single- compared to dual-color blocks.

**Table 7**

*Switching Costs (in %) in Hit Rates*

| Measurement | Group | SC [CI] | *SD* |
|---|---|---|---|
| Pretest | IG | 0.47 [–0.32, 1.25] | 2.24 |
| | CG | –0.245 [–0.84, 0.35] | 1.87 |
| Posttest | IG | –0.40 [–1.18, 0.39] | 2.24 |
| | CG | –0.01 [–0.61, 0.59] | 1.87 |

*Note.* SC = Switching Costs, CI = 95 % confidence intervals, *SD* = Standard deviation, IG = Intervention group, CG = Control group. $N = 74$, $n_{\mathrm{IG}} = 34$ and $n_{\mathrm{CG}} = 40$. Negative values in SCs represent lower hit rates in switch trials compared to repetition trials.

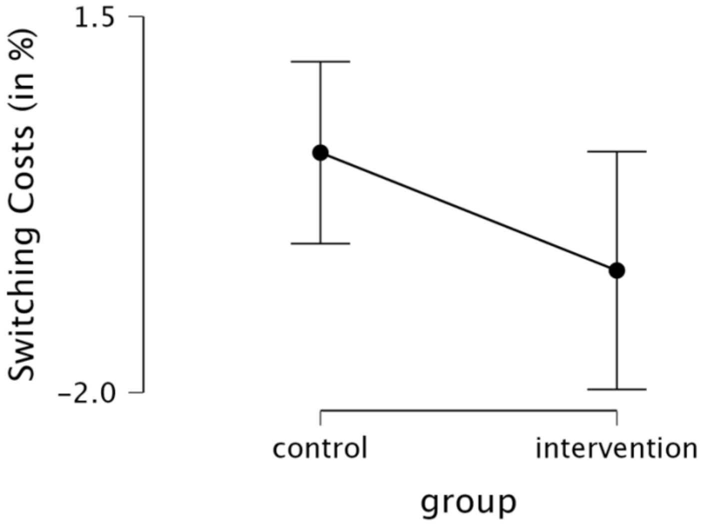
### *Switching Costs*

**Response Times.** The two-way mixed ANOVA revealed that there was no significant main effect of group on SCs in RTs, $F(1, 72) = 2.07$, $p = .155$, $\eta_p^2 = .03$, nor of timepoint on SCs in RTs, $F(1, 71) = 1.07$, $p = .304$, $\eta_p^2 = .01$. We found no significant interaction between group and timepoint, $F(1, 72) = 0.16$, $p = .693$, $\eta_p^2 < .01$. According to a one-sided *t*-test for independent samples, SC differences (SCs at posttest minus SCs as pretest) did not deviate significantly from each other between CG ($M = –1.25$ ms; $SD = 15.10$ ms) and IG ($M = –2.74$ ms; $SD = 17.21$ ms), $t(72)= 0.40$; $p = .346$; $d = 0.09$.

**Hit Rates.** The two-way mixed ANOVA revealed that there was no significant main effect of group on SCs in hit rates, $F(1, 72) = 0.15$, $p = .697$, $\eta_p^2 < .01$, nor of timepoint on SCs in hit rates, $F(1, 71) = 0.65$, $p = .424$, $\eta_p^2 = .01$. We found no significant interaction between group and timepoint, $F(1, 72) = 2.63$, $p = .109$, $\eta_p^2 = 0.04$. SC difference (SCs at posttest minus SCs as pretest) between CG ($M = 0.23$ %; $SD = 2.65$ %) and IG ($M = –0.86$ %; $SD = 3.17$ %) was marginally significant when tested in a one-sided *t*-test for independent samples, $t(72)= 1.62$; $p = .055$; $d = 0.38$. Accordingly, there was a trend that supports the alternative hypothesis that there was a stronger reduction of SCs from pre- to posttest measurements in the IG than in the CG. Figure 5 illustrates the reduction of SCs in hit rates in the IG in comparison to that of the CG.

**Figure 5**

*Reduction of Switching Costs in Hit Rates*



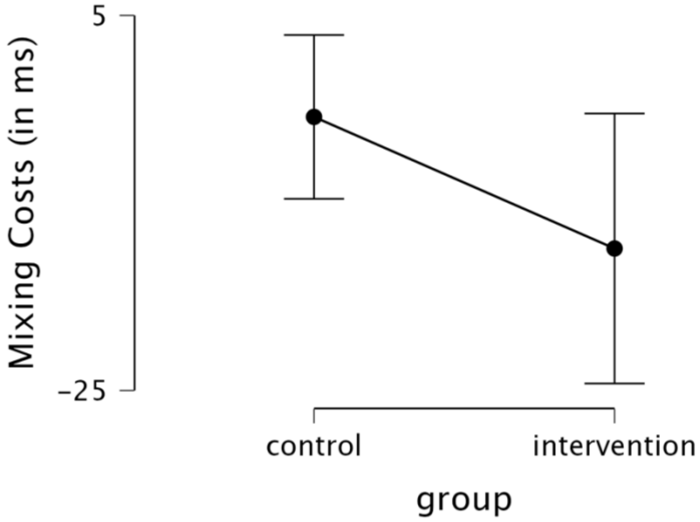
*Note*. Reduction of SCs (%) in hit rates in the IG compared to that of the CG from pre- to posttest measurement.

### *Mixing Costs*

**Response Times.** The two-way mixed ANOVA revealed that there was no significant main effect of group on MCs in RTs, $F(1, 72) = 2.04$, $p = .158$, $\eta_p^2 = .03$. We found a significant main effect of timepoint on MCs in RTs, $F(1, 72) = 7.03$, $p = .010$, $\eta_p^2 = .09$. Planned comparison with a one-sided *t*-test for independent samples revealed a significantly stronger reduction of MCs in RTs from pre- to posttest measurements in the IG ($M = –13.64$ ms; $SD = 30.95$ ms) than in the CG ($M = –3.12$ ms; $SD = 20.48$ ms), $t(72)= 1.75$; $p = .042$; $d = 0.41$. Figure 6 illustrates the reduction of MCs in RTs in the IG in comparison to that of the CG. We found a marginally significant interaction between group and timepoint, $F(1, 72) = 3.06$, $p = .085$, $\eta_p^2 = .04$.

**Figure 6**

*Reduction of Mixing Costs in Response Times*



*Note*. Reduction of MCs (ms) in RTs in the IG compared to that of the CG from pre- to posttest measurement.

**Hit Rates.** The two-way mixed ANOVA revealed that there was no significant main effect of group on MCs in hit rates, $F(1, 72) = 0.08$, $p = .783$, $\eta_p^2 < .01$. We found a significant main effect of timepoint on MCs in hit rates, $F(1, 72) = 5.33$, $p = .024$, $\eta_p^2 = .07$. Difference of MCs in hit rates (MCs at posttest minus MCs as pretest) between CG ($M = 0.23$ %; $SD = 2.65$ %) and IG ($M = –0.86$ %; $SD = 3.17$ %) from pre- to posttest measurement was not significant when tested with a one-sided *t*-test for independent samples, $t(72)= 0.25$; $p = .403$; $d = 0.06$. There was no significant interaction between group and timepoint, $F(1, 72) = 0.06$, $p = .805$, $\eta_p^2 < .01$.

## Discussion

The purpose of this study was to determine if regular Hatha Yoga practice can enhance cognitive performance, particularly the executive functions inhibition and shifting during visual search. To investigate this, we conducted a randomized controlled trial comparing the performance of an IG and a CG on visual search tasks before and after an intervention. The IG participated in an eight-week Hatha Yoga course, whereas the CG received the course after the IG had completed it.

## Suppression

We did not anticipate the intervention to have any effect on RTs. Our investigation revealed that neither group nor timepoint affected RTs. This serves as a precautionary measure to ensure that there are no other general cognitive effects at work here either and indicates that there are no study design flaws.

The behavioral results of our study on inhibition function did not support the idea that Yoga practice improves suppression of distractors either. We expected that, if Hatha Yoga can influence the inhibition function of attention through practice of suppression of distractors, the IG would have fewer FAs in a suppression experiment compared to an CG from pre- to posttest measurement due to increased inhibition of salient and target-similar distractors. This would also have increased the proportion of correct responses (as non-responses are counted as correct in those conditions).

Contrary to our assumptions, FAs did not differ significantly between intervention group and control group from pre- to posttest measurements for either salient distractor or target-similar condition. The same applies to ARs. At least at the behavioral level, participants in the intervention group did not suppress distractors more efficiently than participants in the control group.

In research, reporting null results is just as important as reporting spectacular results; null results contribute equally well to scientific knowledge. The tendency for statistically significant findings to be published over nonsignificant findings leads to a phenomenon referred to as *publication bias* (Rosenthal, 1979). This is a problem since the scientific foundation of psychology is based on concepts such as falsifiability of theories and replicability of study outcomes. This replicability is pointless unless both successful and unsuccessful replications are reported. In the worst-case scenario, publication bias causes a discredited idea to persist in the scientific community for an extended time, although it should actually be discarded. In any instance, the scientific method loses credibility if null results are not recognized as valuable as significant ones.

However, the validity of the stated behavioral outcomes of the suppression experiment is questionable at this point because the experiment conducted was not intended to measure and report suppression using behavioral data (Ferguson & Heene, 2012). In contrast, the use of ERPs improves research technique in this field; previous studies frequently reported attentional capture based on RTs to a target (e.g., Bacon & Egeth, 1994; Lavie & De Fockert, 2005). In other words, the speed of response to the target was utilized to determine whether attention was directed to either a salient distractor or a target-similar distractor. This is an indirect measure of attentional capture or suppression (Sawaki & Luck, 2010) and could only be obtained under conditions that were not part of our experiment, such as when a target and a distractor are presented in the same trial or when cueing effects are considered (Lamy et al., 2004; Lamy & Egeth, 2003). Therefore, only based on the ERP results presented by Szaszkó et al. (currently in preparation) can valid inferences be reached regarding the effects of Yoga on the inhibitory function of visual attention.

Nevertheless, the behavioral data permit us to make some assumptions. While we did not observe the expected significant group differences, we did observe significant large effects of condition on FAs ($\eta_p^2$ = .83) and on ARs ($\eta_p^2$ = 0.85). This indicated that FAs and ARs differed between conditions. According to the contingent involuntary orienting hypothesis, we assumed that target-similar distractors would initially attract attention. Additionally, we expected salient distractors to elicit suppression, following the bottom-up saliency hypothesis. The observed difference suggests that a target-similar distractor initially attracts attention and thus is more likely to elicit a response than a salient distractor, which is suppressed from the outset and thus does not elicit a response – observable in differing FAs and ARs between conditions. This supports our theoretical hypotheses regarding the deployment of visual attention.

There was also a significant effect of time point on FAs with a large effect size ($\eta_p^2$ = .34) and a significant effect of time point on ARs with also a large effect size ($\eta_p^2$ = .34). This indicated that FAs and ARs differed between time points. As training effects in visual search performance have already been discovered, it is conceivable that these effects are the result of repeated practice with a task (Krzepota et al., 2015).

As demonstrated in Table 3, FAs for salient distractors were generally very low (ranging between 0.40 % and 0.85 %). This makes it difficult to distinguish between groups here. However, low error rates in the salient distractor condition suggest that the suppression of the salient distractor was basically successful, which is a precondition for demonstrating this suppression by ERPs.

## Switching

Our hypothesis, that Hatha Yoga practice leads to improved switching between ACSs, was partially supported. Our data did not indicate significantly greater reduction of SCs in RTs in the IG compared to the CG from pre- to posttest measurement. We discovered a marginally significant ($p$ = .055) effect of the intervention on SCs in the hit rates of small effect size ($d$ = 0.38). Accordingly, there was a trend supporting the alternative hypothesis that there was a greater reduction in SCs from pretest to posttest measurement in the IG than in the CG concerning hit rates. The hypothesis that Hatha Yoga practice reduces MCs in RTs was supported by findings showing significantly lower MCs in RTs for intervention group compared to control group from before to after the Yoga intervention with a medium effect size (*d* = 0.41).

Due to the ambiguity of the results, they are only partially in line with previous research. The significantly decreased MCs in RTs and lower SCs in hit rates for the intervention group compared to the control group are consistent with previous research findings that cognitive functions can be trained (e.g., Anguera et al., 2013; Bherer et al., 2008; Davidson et al., 2003; Johann & Karbach, 2020; Karbach et al., 2017; Kray et al., 2012). The significant results also support the previously unexamined hypothesis that Yoga practice, as a form of MBIs, may have effects on cognitive functions. Specifically, it was demonstrated that Yoga practice may enhance the switching function of executive attention. Possible explanations for why this may not have been demonstrated for all hypotheses are discussed in the next section.

## General discussion

### *The Character of the Intervention*

The characterization of the intervention was somewhat contrary to our expectations. We hypothesized that the combination of the physical component of Yoga with bodily awareness and the mindfulness component of MBIs would have an effect on cognitive functions. An extensive body of research suggests that physical activity has positive effects on cognitive performance at every developmental stage. There is evidence that acute as well as chronic aerobic exercise enhances executive function in children in general (Best, 2010), particularly in children with attention-deficit hyperactivity disorder (Gapin & Etnier, 2010) and cognitively challenging exercise improves inhibition function in overweight children (Crova et al., 2014). There is evidence that regular physical activity enhances executive function, as represented in the task switching paradigm, even in young adults (Kamijo & Takeda, 2010; Salas-Gomez et al., 2020). Physical exercise and executive functions have been demonstrated to be associated in older adults (Bixby et al., 2007) and may even influence one another (Daly et al., 2015), to name just a few examples. As indicated at the outset, Yoga also involves significant physical movement. As also indicated in the beginning, focusing on the present moment and actively disregarding distractions has come to be associated with the mindfulness component of Yoga. However, EPQY data indicate that these components were relatively low. The results show that during class, trainers mostly focused on breath and body awareness, followed by acceptance/compassion. Two of the components that we anticipated would result in effects were underrepresented in the intervention. Future research should evaluate whether an intervention that places stronger emphasis on the meditation/mindfulness and physicality components, in addition to bodily awareness, will result in clearer outcomes.

### ***Far transfer***

To further discuss the ambiguity of the results, let us take a look at the idea of far transfer. Woodworth and Thorndike (1901) initially described far transfer. According to their common-elements theory, transfer is dependent on the degree to which two domains contain similar features. Far transfer in this context refers to the generalization of a set of skills across two (or more) domains that are only loosely related, such as arithmetic practice and chess play. In this study, we examined accordingly whether a transfer of cognitive functions practiced in Yoga to the domain of visual attention is possible.

According to common-elements theory, far transfer occurs much less frequently than near transfer, which is the advantage of practicing one arithmetic problem to solve another arithmetic issue. There are critical voices who question whether far transfer exists at all. Sala and Gobet (2017) report the results of three reviews: two on the cognitive correlates of expert performance and one on the effectiveness of cognitive training in chess play, music, and WM training. Especially in our education system, far transfer is a present topic, as interventions that could improve students' general cognitive skills across domains are of great interest. Sala and Gobet (2017) examined the population of healthy children and tested the hypothesis of whether WM training can improve cross-domain skills (e.g., fluid reasoning/intelligence), which then generalize to other cognitive and academic skills (e.g., mathematics). They present findings that raise doubt on the efficacy of executive skills training for cognitive or academic skills and, by extension, on the far transfer of these skills to other domains. Rarely are positive benefits observed, and when they are, they are modest at best.

Our results align with these findings. The behavioral data on distractor suppression imply that there is no far transfer, as the intervention group that practiced those cognitive functions that would have been transferable performed no better than a passive control group.

Comparing the transfer findings of both strategy training and extended practice, Zelinski (2009) proposed that far transfer can be observed. Studies on extended practice demonstrated even stronger far transfer effectiveness than those on strategy training. Extended practice has been utilized to train memory, dual-task performance, attention, and discrimination skills - the research topics with which our study is also concerned. However, these trainings do not attempt to enhance or promote the development of new skills, as educational psychology does; rather, they are designed to rehabilitate skills that are thought to have declined with age (e.g., Winocur et al., 2007).

Our ambiguous results, both between experiments and within the task switching experiment, may be explained by the fact that this cognitive process is capable of long-distance transfer, but is more successful at recuperating these skills. Thus, the effect of far transfer seems to be very dependent on population, training content, and goals of the training, and is not easy to detect. Future research should continue to define the extent to which and when far transfer can be achieved.

## Limitations

Various limitations may have influenced the study's findings. First, it must be noted that the screening was based on self-report. Previous regular Yoga practice was a study exclusion criterion that could not be verified. If participants have regular Yoga experience, the cognitive training benefits from before to after the intervention may be diminished or nonexistent compared to those without Yoga experience. The option to engage in a two-month private Yoga class in a studio for free could have been an alluring inducement not to answer the screening form truthfully.

The nature of our sample represents a further limitation of our study. Despite the fact that our study was open to persons from diverse educational backgrounds and a wide range of ages, the majority of our sample comprised of students due to mainly recruiting through university platforms. Additionally, they were predominantly female, which was less a result of the recruitment approach and more a result of the individuals who were potentially interested, but nonetheless limited the sample. Future research should evaluate the impact of Hatha Yoga on executive functioning in diverse populations with, for example, a higher number of males and varied levels of education.

Even though we aimed for a big enough sample size to detect potential effects with a power of 80 %, the amount of useable data shrank to 74 data sets since a relatively high number of participants only completed the measurements partly, for example only pretest measurements, or did not participate in at least two yoga sessions per week for three consecutive weeks if belonging to the IG. While this was partly due to consequences of COVID-19 (non-attendance of measurements, SSC, or yoga sessions due to infection), it could also be due the relatively high commitment character of our study: Since we aimed at avoiding methodological issues of former yoga intervention studies, for example by

> choosing a time-consuming SSC procedure and a high frequency of yoga sessions, our study could be seen as quite time consuming for participants in general. While we tried to avoid high drop-out rates through detailed briefing of participants and reasonable financial compensation, future studies might consider investigating less time-consuming yoga interventions or higher financial compensations. (Maiworm, 2022, pp. 43-44)

However, less time-consuming interventions may be challenging: To design the study and determine the required amount of Hatha Yoga practice, we had to consult existing research on the effects of the practice. Since there was nothing comparable research on the relationship between Yoga and cognitive function, and because the study also explored the relationship between Yoga, stress, and anxiety, we referred to literature on this topic.

> While a review on the effects of Yoga in general on stress did not find a relationship between the amount of Yoga practices and effect size (Breedvelt et al., 2019), a review on the effects of Hatha Yoga on anxiety did find a positive association between the intervention´s efficacy and the total number of Yoga classes (Hofmann et al., 2016). (Maiworm, 2022, p. 44)

Results like this should be taken into account when planning Yoga interventions, and it would be of great help to optimize interventions by determining at what number of practice hours an intervention elicits beneficial effects on cognitive functions.

Furthermore, we did not include an active control group to control for intervention-unspecific effects, such as social components, or to distinguish the intervention from other physical activities. Therefore, future research should evaluate the efficacy of Hatha Yoga in contrast to other active therapies for the enhancement of cognitive processes, using a high-quality scientific design, thereby contributing to the appropriate implementation of various interventions.

## Conclusion

It was investigated whether yoga, as a physically oriented form of MBI, can influence essential cognitive functions. Our findings contribute to the field of Yoga as an intervention by elucidating the effects of Hatha Yoga on executive functions, specifically inhibition and task switching. We have demonstrated that Hatha Yoga practice can contribute to the reduction of mixing costs and switching costs in a limited way. We could not report any effect of Hatha Yoga practice on behavioral measures of inhibition function. We propose that optimization of the intervention would be required for conclusive results. In addition, it would be worthwhile to explore the effects of Yoga practice on the rehabilitation of the assessed skills.

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# List of Abbreviations

| | |
|---|---|
| ACS: | Attentional control setting |
| ANOVA: | Analyses of Variance |
| AR: | Accuracy rate |
| CG: | Wait list control group |
| EEG: | Electroencephalography |
| EPYQ: | Essential Properties of Yoga Questionnaire |
| ERP: | Event-related potential |
| FA: | False alarm |
| IG: | Intervention group |
| MBI: | Mindfulness-based intervention |
| MC: | Mixing costs |
| N2pc: | N2-posterior-contralateral |
| PD: | Distractor positivity |
| RT: | Response time |
| SC: | Switching costs |
| SM: | State mindfulness |
| SSC: | Saliva sample collection |
| TM: | Trait mindfulness |
| UoV: | University of Vienna |
| WM: | Working memory |

# Appendix

## Abstract (English)

Visual search, as a component of visual attention, is an indispensable aspect of everyday living. Therefore, it would be of interest to learn how to enhance this cognitive function. As a mindfulness-based technique, meditation has been shown to improve cognitive processes, particularly executive functions. We investigated whether Yoga, as a physically oriented kind of mindfulness-based interventions, may also contribute to the enhancement of executive functions, namely task switching and distractor suppression in visual search tasks. In a randomized controlled trial, we investigated the effects of an eight-week Hatha Yoga intervention on inhibition and task switching in 74 participants. Our hypotheses were confirmed in part: Pretest to posttest measurement revealed, as predicted, a higher reduction of mixing costs in task switching for the intervention group compared to the control group. The intervention group had a greater reduction in switching costs from the pre-test to the post-test than the control group. Behavioral results revealed no effect of the intervention on inhibitory function. Future research can expand on these findings by focusing more on relevant intervention components such as mindfulness and physical activity.

*Keywords:* visual attention, visual search, Hatha Yoga, mindfulness-based interventions, executive functions, task switching, inhibition

**Zusammenfassung (Deutsch)**

Visuelle Suche als Bestandteil der visuellen Aufmerksamkeit ist ein unverzichtbarer Aspekt des täglichen Lebens. Daher wäre es von Interesse zu erfahren, wie diese kognitive Funktion verbessert werden kann. Als achtsamkeitsbasierte Technik verbessert Meditation nachweislich kognitive Prozesse, insbesondere exekutive Funktionen. Wir untersuchten, ob Yoga, als eine körperlich orientierte Form der achtsamkeitsbasierten Intervention, auch zur Verbesserung exekutiver Funktionen beitragen kann, nämlich zu Wechseln zwischen Aufgaben und zur Unterdrückung von Distraktoren bei visuellen Suchaufgaben. In einer randomisierten kontrollierten Studie untersuchten wir die Auswirkungen einer achtwöchigen Hatha-Yoga-Intervention auf Inhibition und Wechseln zwischen Aufgaben bei 74 Teilnehmenden. Unsere Hypothesen wurden zum Teil bestätigt: Die Messung von Pretest zu Posttest ergab, wie angenommen, eine höhere Reduktion der Mischkosten bei Wechseln zwischen Aufgaben in der Interventionsgruppe im Vergleich zur Kontrollgruppe. Die Interventionsgruppe hatte eine größere Reduktion der Wechselkosten von Pretest zu Posttest als die Kontrollgruppe. Die verhaltensbasierten Daten zeigten keine Auswirkungen der Intervention auf die Inhibitionsfunktion. Künftige Forschung könne diese Ergebnisse erweitern, indem sie sich stärker auf relevante Interventionskomponenten wie Achtsamkeit und körperliche Aktivität konzentriert.

*Schlüsselwörter:* Visuelle Aufmerksamkeit, visuelle Suche, Hatha Yoga, achtsamkeitsbasierte Interventionen, exekutive Funktionen, Aufgabenwechsel, Inhibition