Effects of Visually Entrained Alpha-Frequencies and Individual Alpha Frequencies on Near-Threshold Stimulus Discrimination Task Performance

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Abstract

Rhythmic stimulus presentation is a concept used in multiple sensory modalities and widely used; in the EEG, rhythmic oscillations in the alpha range (7 - 14 Hz) are one of the most prominent patterns. Interindividual differences in these rhythms can be demonstrated, characterizing complex neural activity into an easily measurable marker. Individual resting state alpha frequencies (IAF) and their characteristics (power, phase, frequency) have been shown to correlate with complex cognitive functions, such as the attentional blink (MacLean, Arnell, & Cote, 2012) or temporal visual perception (Ronconi, Busch, & Melcher, 2018). By presenting rhythmic stimuli, oscillatory activity in the brain can be entrained and subsequentially influences stimulus processing (Mathewson et al., 2012). The present study aimed to examine to what extent IAF and visually entrained frequencies influence the processing of near-threshold (masked) stimuli. No effects of IAF or entrainment to different frequencies (8, 12, 30 Hz) could be found. This result demonstrates that the frequency of rhythmic brain activity itself did not proove to be a reliable indicator of the temporal resolution of the visual system in the discrimination task used here. The speed of visual processing as examined by briefly presenting masked stimuli does not seem to be connected to the dominant alpha frequencies during resting states. Further examination of IAF and visual alpha oscillations is required to examine their connection to the speed of visual processing.

Zusammenfassung

Rhythmische Stimuluspräsentation ist ein sinnes-übergreifendes und weit verbreitetes Konzept; rhythmische Oszillationen im EEG im Alpha-Wellen-Bereich (7 - 14 Hz) sind ein markantes Muster im EEG. Interindividuelle Unterschiede in diesen Rhythmen können beobachtet und als einfach messbarer Marker komplexer neuraler Aktivität verwendet werden. Individuelle Alpha-Frequenzen (IAF) und ihre Eigenschaften (Power, Phase, Frequenz) korrelieren mit verschiedenen kognitiven Prozessen wie dem *attentional blink* (MacLean et al., 2012) oder zeitlicher visueller Wahrnehmung (Ronconi et al., 2018). Oszillatorische Aktivität kann hervorgerufen werden, indem rhythmische Stimuli präsentiert werden, welche als Folge die Stimulusverarbeitung beeinflusst (Mathewson et al., 2012). Die vorliegende Studie untersuchte, in welchem Ausmaß IAF und visuelles Entrainment in verschiedenen Frequenzen (8, 12, 30 Hz) die Verarbeitung von maskierten, schwer erkennbaren Stimuli beeinflusst. Kein Effekt der Entrainment-Frequenz konnte gefunden werden. Dieses Ergebnis impliziert, dass die Frequenz von rhythmischen Gehirnaktivitäten keinen Hinweis auf die zeitliche Auflösung des visuellen Systems (in der hier verwendeten Diskriminationsaufgabe) gibt. Die Geschwindigkeit der visuellen Verarbeitung (gemessen an sehr kurz präsentierten Reizen) scheint keine Verbindung zu den vorherrschenden Alpha-Frequenzen im Ruhezustand zu haben. Weitere Untersuchungen der IAF und von visuellen Alpha-Oszillationen sind nötig, um die Verbindung dieser Phänomene zur zeitlichen Auflösung des visuellen Systems festzustellen.

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1 Introduction

To examine the limits of human visual perception, a large number of studies use masked stimuli amongst other paradigms. Masked stimuli can also be used to investigate the temporal aspect of visual processing or the processing of stimuli near the threshold of conscious perception. Masking can be used to render a stimulus impossible to report consciously by presenting other stimuli before or after it (forwards or backwards masking). However, under certain circumstances, the target stimuli still seem to be processed by the visual system (e.g., priming by masked stimuli: Leuthold & Kopp, 1998). Presenting target stimuli for only a few milliseconds and additionally masking them usually results in relatively low detection and discrimination rates close to chance; yet some people still reach very high performances. Natural interindividual differences in perceiving masked stimuli exist, but where do they come from, and to what extend can they be predicted? Since the physical properties of the stimuli are identical, some explanation must come from interindividual differences in how these stimuli are processed. To experimentally examine the perception of such stimuli, one approach would be to reduce the effect of masking but at the same time to keep the target stimulus presentation unchanged. A recent line of studies suggests that it is possible to decrease the effect of masking by previous rhythmic presentation of stimuli (also called entrainment) at the frequency of *alpha oscillations* (Mathewson, Gratton, Fabiani, Beck, & Ro, 2009; Mathewson et al., 2012).

1.1 Alpha oscillations

Alpha oscillations are known since electroencephalography (EEG) has first been used to examine brain activity (Berger, 1929). Usually, they are described to be oscillatory processes in the frequency range of around 10 Hz, but this classification is subject to an ongoing discussion; some researchers suggest using a wider range to define the alpha band (8 - 12 Hz as in, e.g., Haegens, Cousijn, Wallis, Harrison, & Nobre, 2014) or to define the alpha range for each person individually (as done by, e.g., Ronconi et al., 2018). Oscillatory activity in the alpha frequency band is subject to a wide range of studies investigating its source (Sadaghiani & Kleinschmidt, 2016) and its function in the brain (Clayton, Yeung, & Cohen Kadosh, 2018), see also Bazanova & Vernon (2014) for an overview.

One theoretical approach sees oscillatory alpha activity as an active process that inhibits task-irrelevant regions in the brain, as already indicated by Berger (1929): If subjects do not have a task to work on and additionally keep their eyes closed, the occipital alpha rhythm gets more pronounced. This can be interpreted as a higher activity of an inhibitory mechanism which suppresses visual processing activity, since no visual information is received (see also Clayton et al., 2018).

According to the *oscillatory selection hypothesis*, oscillatory processes ensure processing of rhythmic stimuli at the most excitable state of the sensory system (for an overview, see e.g., Frey, Ruhnau, & Weisz, 2015). This is also closely related to the concept of *active sensing* (Schroeder & Lakatos, 2009), which states that the sensory system adjusts its sampling of external stimuli to improve allocation of attentional ressources. Both accounts are corroborated by findings that give oscillatory processes, especially alpha oscillations, a role in explaining the attentional blink (MacLean et al., 2012; Zauner et al., 2012) or the integration or segregation of succesive stimuli (Ronconi et al., 2018; Samaha & Postle, 2015). In a review, Hanslmayr, Gross, Klimesch, & Shapiro (2011) presented additional arguments that a rhythmic presentation of stimuli can 'tune' temporal attention.

This study focusses on the frequeny of these alpha oscillations. Assuming that alpha oscillations indeed represent oscillatory processes that are linked to visual processing, the speed of these processes could be indicated by the frequency of the resulting oscillatory patterns. Thus, higher processing speed (in this case higher temporal resolution in the visual domain) could be indicated by higher alpha frequencies; the present study aims to explore this reasoning.

1.2 Individual alpha frequencies (IAF)

Frequency spectra in the alpha range differ between individuals in many aspects like frequency distribution or peak frequency, but remain stable within subjects (Kondacs & Szabó, 1999). As a result, a marker of interindividual differences in the alpha band is the individual alpha frequency (IAF), sometimes called individual alpha peak frequency. This typically denotes the most prevalent frequency in the alpha range in terms of its power of an individual, yet there is no consensus on how to determine this frequency (see e.g., Corcoran, Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2018). Individual alpha frequencies (IAF) seem to be indicators of a wide variety of cognitive processes, such as spatial or temporal visual attention and working memory (Frey et al., 2015; Haegens et al., 2014) or visual evoked potentials (Koch, Koendgen, Bourayou, Steinbrink, & Obrig, 2008). When examining individual alpha frequencies (IAF) and the entrainment of alpha frequencies, most studies focus on the resulting power spectra and examine stimulus processing with regard to the power of the frequencies in the alpha band (Kizuk & Mathewson, 2017), or explore how the phase of the alpha rhythm over posterior brain regions prior to the stimulus presentation can be used to predict visual detection performance and cortical activation levels (Mathewson et al., 2009).

The present study focusses on a different property of alpha oscillations, that is adressed to a much lesser extent: The most prevalent frequency itself, as opposed to the usual focus on the power or phase of alpha oscillations. The individual alpha frequency (IAF) will be used in both parts of this study as a possible indicator of performance of the visual system, with the goal of providing a possible predictor of interindividual performance differences in a given task.

1.3 Present study

The present study aims to examine the dependence of near-threshold stimulus discrimination performance on visual alpha oscillations and individual alpha frequencies (IAF). The goal is to investigate how well certain near-threshold stimuli are processed and if this is influenced by interindividual IAF differences and intraindividual experimentally manipulated alpha oscillations.

This study consists of two parts: In the first part, the results of an experiment in the domain of unconscious processing are reanalyzed to check for a general influence of interindividual differences of resting state alpha frequencies on task performance. A positive correlation between these two measures is expected, since the reasoning of this study assumes that a higher IAF is an indicator of faster oscillatory processes in the visual system, which could translate into higher temporal resolution and thus, higher performance in the given tasks.

The second part introduces intraindividual entrainment of alpha frequencies in the visual cortex as an experimental manipulation and the influence of different entrainment frequencies on stimulus discrimination performance. Jones, Moynihan, MacKenzie, & Puente (2002) showed that in-phase presentation of an auditory target stimulus with a preceeding rhythmic sequence results in highest task performance. This idea of rhythmic entrainment and phase offset in stimulus presentation is used in the second part of this study, albeit exclusively focussed on the visual modality. The main hypothesis is that entrainment to higher frequencies within the alpha range results in higher discrimination performance.

2 Part One: Re-Analysis of Existing Data

This first section is an exploratory attempt to investigate the possible effect of the individual alpha frequency (IAF) on near-threshold discrimination performance.

2.1 Motivation

The experiment described below has been designed to explore the processing of near-threshold masked priming stimuli (horizontal or vertical lines) that are followed by congruent or incongruent target stimuli with behavioral measures and EEG. Such briefly displayed primes and their processing are subject to a number of studies especially in the domain of conscious and unconscious processing (e.g., Sumner, 2008). The usual results show that participants are able to discriminate the masked prime stimulus only slightly above chance level, with very few participants scoring much higher than others. This indicates that this task is an appropriate example of stimuli being presented near-threshold and thus can be used to explore interindividual performance differences.

The goal of this section is to re-analyze the data acquired in this experiment with regard to the individual participants' performance and their resting state IAF. It has been shown that the phase of alpha rhythms in the visual cortex can predict visual detection and even further cortical activation (Koch et al., 2008; Mathewson et al., 2009). Other results indicate that resting state IAF correlates with the ability to discriminate two successively and fast presented flashes from a single flash (Samaha & Postle, 2015), and that IAF can predict the effect of flickering at a certain frequency on task performance during a flanker task (Gulbinaite, Viegen, Wieling, Cohen, & VanRullen, 2017). Alpha oscillations and IAF seem to have some predicitve value to how participants process and perceive certain stimuli.

The main assumption is that individual alpha frequencies can be used to predict which subjects reach a higher performance in diffcult tasks (in this study: tasks involving very briefly presented stimuli). In terms of the *active sensing* account mentioned above (Schroeder & Lakatos, 2009), individuals with a higher performance in such tasks could achieve these results by having a higher temporal resolution of their visual system, which in turn could be indicated by higher more dominant alpha frequencies (IAF) over the visual cortex. To explore this hypothesis, the data of this experiment are analyzed to check for a general positive correlation between IAF and task performance. The results are a first indicator whether IAF values can be used as a predictive measure for the participants' performance.

To investigate this, the present study first compares two different methods to calculate the IAF for each participant. Since it has been shown that IAF varies between individuals and sometimes exceeds the range of 8 - 12 Hz (Haegens et al., 2014), the present study uses an extended alpha band of 7 - 14 Hz. One commonly used method to calculate the IAF is to look for a peak in the alpha range in the power spectral density (PSD) distribution. As an alternative to this commonly critizized method (see e.g., Goljahani et al., 2011), a second method, based on a 'center of mass' account is used. Although many other methods are proposed and discussed (e.g., Goljahani, Bisiacchi, & Sparacino, 2014; Corcoran et al., 2018), for simplicity, only the center of mass method is explored in this study. Since the center of mass method takes into account more information of the PSD distribution, it is the preferred method for this study (see 2.3.1). Both methods should result in approximately the same IAF values with no one method consistently and significantly over- or underestimating the other.

After this, the data acquired in this experiment is used to check for a positive correlation between IAF and performance measures. The hypothesis is that subjects with higher IAF values should also show a higher performance in the stimulus discrimination task, as a higher prevalent alpha frequency could be an indicator of a higher temporal resolution of the visual system and hence a better task performance.

2.2 Methods

The following sections describe the experiment conducted in the context of a seminar for students of the cognitive science Bachelor's degree. The goal of this experiment was to investigate subliminal priming of responses using simple line stimuli with behavioral measures and EEG.

2.2.1 Participants

Thirteen volunteers (seven female, six male; mean age 21.9 years; range 18 - 29 years) participated in this experiment. All subjects had normal or corrected-to-normal vision (visual acuity range 0.8 - 2.4), tested with the Freiburg Visual Acuity and Contrast Test FrACT (Bach, 2006). Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield (1971); see Appendix Fig. A.1), which classified two participants as left-handed. Subjects received money (12€ per hour) or course credits as compensation. Since this experiment was part of a seminar, only five participants were completely naïve to the task.

The data of two (non-naïve) participants could not be used due to errors in the stimulus presentation, which changed the task difficulty and thus heavily influenced these subjects' performance. All following analyses were conducted on the remaining eleven subjects.

2.2.2 Data acquisition

The EEG and behavioral data was acquired by placing the participants in an electromagnetically isolated, soundproof chamber (Desone A:Box Size C, Desone Modulare Akustik Ingenieurgesellschaft für Schalltechnik mBH, Berlin) with the monitor being the only light source.

The stimuli were presented on a ViewPixx/3D Lite monitor (refresh rate 120 Hz, VPixx Technologies Inc., Canada) at a distance of 85 cm using MATLAB 64 Bit (MATLAB and Statistics Toolbox Release 2017a, The MathWorks, Inc., Massachusetts) and the Psychophysics Toolbox extensions (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Participants responded using dedicated response buttons (ResponsePixx Handheld, VPixx Technologies Inc., Canada). Participants were instructed to only use their left and right index fingers to react with the left and right button.

EEG data was acquired using the BrainVision actiCHamp system in connection with 64-channels EasyCap, using PyCorder V1.0.9 to record and store the data (all: BrainProducts GmbH, Germany).

The following electrodes were recorded (placement according to the international standard 10-20 system) with a sampling rate of 500Hz: FP1, FP2, FZ, F3, F4, F7, F8, FT9, FT10, FC1, FC2, FC5, FC6, C3, C4, CZ, T7, T8, TP9, TP10, CP1, CP2, CP5, CP6, P1, P2, P3, P4, P7, P8, PZ, PO3, PO4, POZ, O1, O2, OZ (see Figure 1). Additional electrodes were placed below and next to the left eye as vertical and horizontal EOG, respectively. Data were recorded without a reference and re-referenced off-line to the left and right mastoid average (electrodes TP9, TP10). Relevant electrode impedances (electrodes used for individual alpha frequency calculation and referencing) were kept below 15 kΩ.

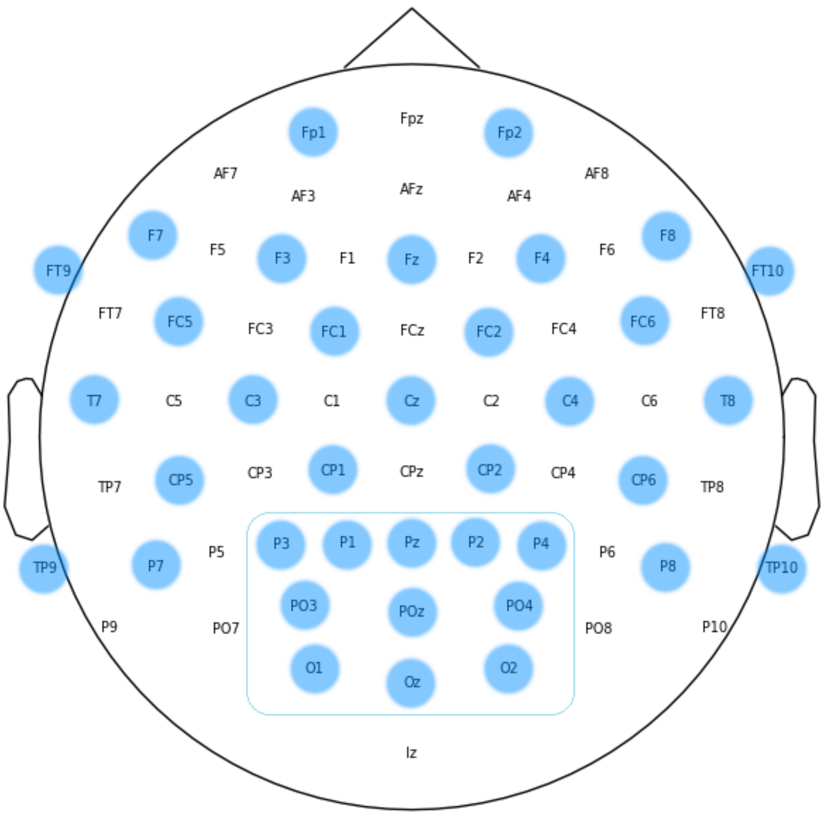

Figure 1: Electrode locations. The electrodes highlighted in blue have been recorded in this experiment. The electrodes used for the EOG are not pictured. The box in the occipital region of the head indicates the electrodes that were used to calculate the individual alpha frequencies.

2.2.3 Experimental procedure

All subjects participated in four experimental blocks that were recorded separately: resting state recording '*pre-experiment*' (1), experimental task - '*indirect task*' (2), experimental task - '*direct task*' (3) and resting state recording '*post-experiment*' (4). After that, participants filled in a short questionnaire related to the experimental tasks.

Resting state (1, 4). Participants were asked to sit calmly with their eyes closed for both resting state recordings. They were insructed not to keep track of the time by counting but to just wait and relax for two minutes. Recording started after the door was closed and visual inspection of the on-line EEG recording indicated closed eyes and no major eye movement. After two minutes, the experimenter stopped the EEG recording and opened the door to the booth.

Experimental task - indirect task (2). After a general description of the task (see Appendix, Fig. A.2), subjects were presented with a practice block, where they had to react to the target stimulus at the end of each trial (see section 2.2.4). During this block, the experimenter was present in the booth and encouraged the participant to react as fast as possible and to not be irritated if they made a mistake. After the practice block, the experimental task started. It took 10 minutes and was split into three blocks with self-administered breaks for the participants. Trials with wrong responses or responses that were too fast or too slow were repeated later in the experiment, so that for each participant, the same amount of 192 valid trials was recorded.

Experimental task - direct task (3). After a short break, participants were now informed of the prime stimulus and were instructed to react to this stimulus with the corresponding button (see Appendix, Fig. A.3). After a practice block with the experimenter present, participants were encouraged to react as correctly as possible to the prime and to ignore the target stimulus. This experimental task took 10 - 15 minutes and was split into three blocks with self-administered breaks. Only trials with responses that were too fast or too slow were repeated later, so that for each participant, the same number of valid trials (192) was recorded.

2.2.4 Stimuli and trial structure

Each trial began with the presentation of a fixation cross (viewing angle 1°), which was present for 415 ms (see Fig 2). After this, a sequence of forward mask, prime and backwards mask were presented rapidly (mask duration: 67 ms, prime duration: 33 ms). Then the target stimulus was shown for 200 ms, after which subjects could answer by pressing one of the two assigned buttons. The minimal reaction time allowed was 200 ms, measured from the onset of the target. In the indirect task, participants had up to 1000 ms to respond to the target, whereas in the direct task, where participants had to react to the prime stimulus, reaction times up to 5000 ms were possible. If participants responded with the wrong button in the first task, a short warning was shown after the reaction. Another warning indicated responses that were too slow in both tasks.

The masking stimulus was constructed as follows, see also Sumner (2008): 30 random lines were placed in the central region of the screen, where all simuli were presented. The length of these lines varied from 1 to 3 times the viewing angle of 1°, the orientations of the lines were randomly chosen values (diagonally oriented 22.5°, 45°, 67.5° to the right or left) to not include vertical or horizontal lines (0°, 90°) as used in the prime and target stimuli.

The prime and target stimuli were parallel lines of length 1° (viewing angle), with a distance of 1°, which could be presented congruently (prime and target with identical orientation) or incongruently.

All stimuli were presented in white on black background.

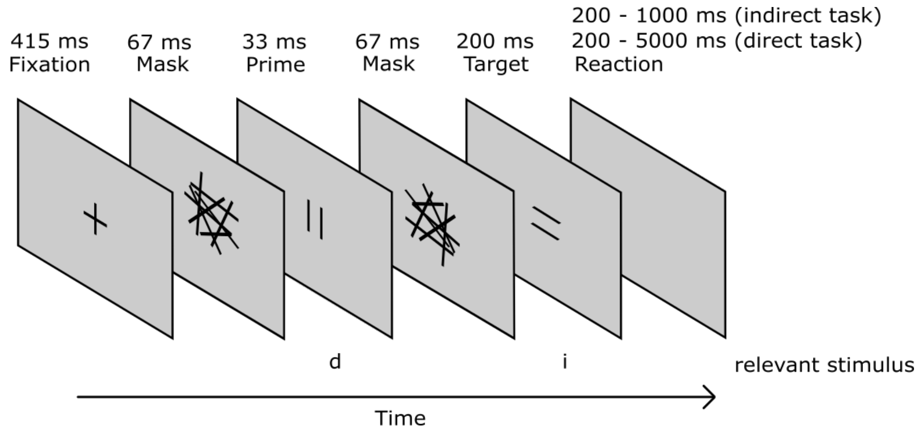

Figure 2: Schematic trial structure. In the first task, the *indirect task*, the participants had to react to the target stimulus, marked with an 'i' in the image. This task was a reaction time task, so participants had to react as fast as possible. The second task was the *direct task*, where participants had to discriminate the prime stimulus, marked with a 'd'. Participants had up to 5 seconds to respond, but they should do so as correctly as possible.

2.3 Results

The goal of this first part of this study was to re-analyze the data acquired in the experiment mentioned above in order to look for a general correlation between stimulus discrimination performance and individual alpha frequency (IAF). Section 2.3.1 examines the EEG data and compares two different methods to calculate the IAF. The acquired frequency values and their correlation with the performance in the direct task of the experiment are inspected in section 2.3.2.

2.3.1 Comparison of IAF determination methods

A resting state recording was acquired before and after the experiment. Since only the first recording was not influenced by the experimental procedure, this was the preferred data to determine the individual alpha frequencies. The following analyses take into account only these pre-experiment resting state recordings.

All resting state EEG recordings were shortened to two minutes and visually inspected for artifacts, but no recording contained artifacts that would influence the frequency analysis. The raw data was then processed using the MNE software in python (Gramfort et al., 2013). After re-referencing (left and right mastoid average, electrodes TP9, TP10), a subset of electrodes over the visual cortex was selected for the calculation of the individual visual alpha frequencies, the selected electrodes were: P1, P2, P3, P4, PZ, PO3, PO4, POZ, O1, O2, OZ (see Fig. 1). The power spectral density (PSD) distribution for each recording was calculated using the method *psd_welch()* as implemented in the *time_frequency*-module in MNE (n_fft = 4096, which resulted in an effective window size of 8.2 s). An extended frequency range for the alpha band was used (7 - 14 Hz). The resulting PSD distribution was used for further analysis.

Two different methods were applied to calculate the individual alpha peak frequency (IAF). The first method was to select the frequency with the highest power in the extended alpha spectrum (7 - 14 Hz), called here the 'peak' method. The second method took into account the complete alpha spectrum provided (7 - 14 Hz) and the according density distribution, using a center of mass method of the *ndimage*-module for SciPy (Jones, Oliphant, & Peterson, 2001).

A Shapiro-Wilk test for normality indicated that the differences between these two measurement methods for each participant were normally distributed, $W(11) = 0.93$, $p = .40$. The following paired samples t-test showed that the difference between the IAF values acquired by the peak method ($M = 10.24$, $SD = 0.82$) and by the center of mass method ($M = 10.12$, $SD = 0.57$) was not significantly different from zero for each participant, $t(10) = 1.08$, $p = .30$. So for the following analyses, the center of mass method was used to calculate the IAF measures as valid estimates for the dominant visual alpha frequency. Since this method provided a more informed measure of the IAF than simply choosing the peak of the distribution (as discussed in more detail by Goljahani et al., 2011), this was the preferred method and was used for all further analysis. This method did not rely on the presence of peaks in the EEG spectrum but yielded similar results as the peak method. Additional visual inspection of the individual power density distributions confirmed that the center of mass method is a more appropriate measure (see Fig. 3).

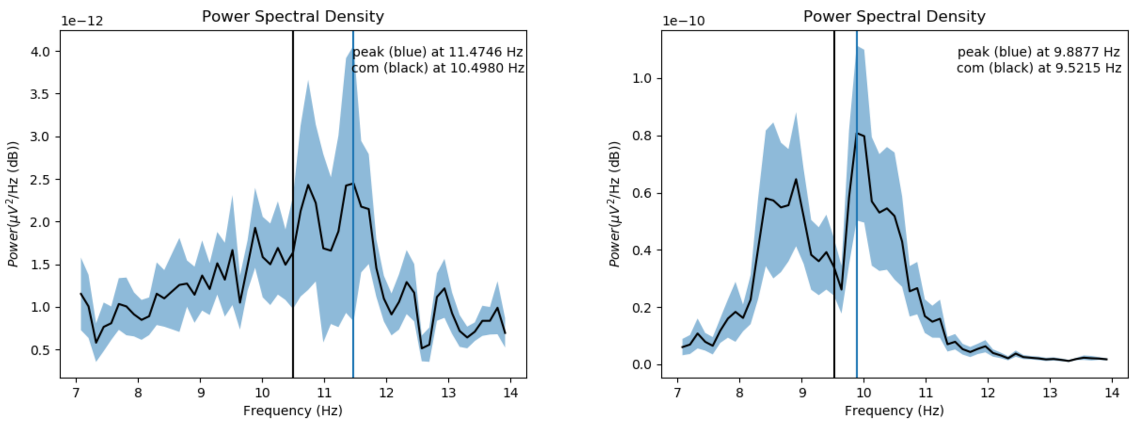

Figure 3: Comparison of peak and center of mass method for IAF determination. The left panel shows an example of a subject with no clear peak of power in the extended alpha region. The center of mass method (black) takes into account this broad distribution, as opposed to the peak method (blue). The right panel demonstrates that the center of mass method (black) adjusts for power distributions with multiple peaks. The plots show the mean power over the entire 2-minute recording averaged over the selected electrodes, with the shaded regions indicating the standard deviation. Note the difference in scale of the y axis, indicating a difference in absolute power of the frequency spectrum.

2.3.2 Correlation analysis

The number of correct and incorrect responses for each participant were used to calculate a mean performance value for the given task. In result, for each participant an IAF value and a performance value were obtained. Since the frequency resolution for acquiring an IAF value is limited by the parameters of the Fourier transformation (e.g., windows size, see 2.3.1), repeated IAF values for different participants were expected, so only certain discrete values were possible. As a result, the Spearman rank correlation coefficient was used to check for a positive correlation between IAF and task performance.

The data of this experiment do not support the main hypothesis of a positive correlation of individual alpha frequencies (IAF) and general task performance. The Spearman correlation indicated no significant positive association between these measures, $\rho_S(8) = 0.046$, $p = .447$.

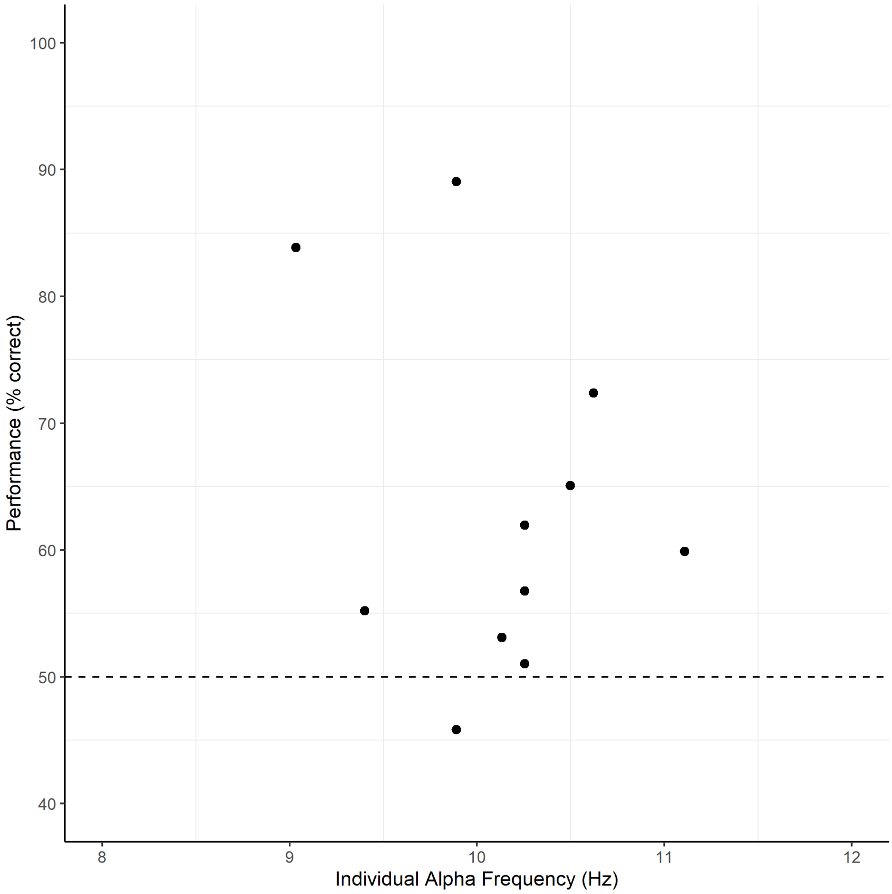

Figure 4: Scatterplot of performance values and individual alpha frequencies. Each datapoint corresponds with one participant in this experiment. The dashed line indicates chance level of performance (50%).

2.4 Discussion

The goal of this part was to reanalyze existing data from a near-threshold stimulus discrimination experiment in order to check for a positive correlation between the individual alpha frequency (IAF) and the subjects performance in the task.

In order to find an appropriate measure for the IAF based on a two-minute resting state EEG recording, two different methods were applied. The first method was a plain peak selection in the alpha band of the power spectrum, the second measure was a center of mass method. As indicated above, the center of mass method obtains a more informed value by taking into account the general distribution of power in the alpha range and thus was also used for the second part of this study. Using the center of mass method also results in an advantage over using the power of a frequency spectrum as a measure of the dominant alpha frequency, as commonly used in research: The absolute power calculation can differ highly between individuals, since this measure depends on the strength of the electrical field and the sensitivity and impedance for each electrode. As can be seen in Fig. 3, the calculation of the dominant frequency is not influenced by the absolute power values of the frequency spectrum. However, it must be kept in mind that the IAF measures always result from inspecting many different oscillatory processes in the same region of the brain, so that singular values extracted from such a PSD distribution always contain less information than the full distribution. As indicated above, calculation methods for IAF are subject to an ongoing discussion, as is their nature and value as a marker of neural activity.

The present data did not show a correlation of IAF and task performance. Multiple factors could have caused this result: The experimental task was not designed with the hypothesis of a correlation between visual IAF and task performance in mind, but rather to explore unconscious processing of near-threshold stimuli. This design resulted in a small sample size ($n = 11$) which could obscure a potential correlation. A solution for this would be to compare other studies that yield a similar measure for performance and the subjects' IAF values. The problem is that this requires the experimental designs to be comparable; furthermore the present study does not take into account different kinds of stimuli. Which stimuli are used could have a significant influence on how well the IAF can be used as a predictor of performance.

Altogether, due to the exploratory nature of this section, no concrete conclusions should be drawn from the results presented here. Whether or not higher IAF values are an indicator of the processing speed of the visual system, and to what extent this can be examined using tasks like the above should be adressed in further studies.

3 Part Two: Experimental Manipulation of Alpha Frequencies

This second section attempts to introduce visual rhythmic entrainment as an experimentally manipulated variable. The goal is to explore the influence of visual entrainment to high and low frequencies in the alpha range on the performance of subjects in a task that requires discrimination of near-threshold stimuli.

3.1 Motivation

Ronconi et al. (2018) showed that auditory entrainment to different frequencies results in different effects on visual temporal resolution: Entrainment to higher frequencies improved segregation of visual stimuli, while entrainment to lower frequencies improved integrated perception of the same stimuli. The authors entrained to frequencies adapted to each participants' IAF, resulting in a low (IAF - 2 Hz) and a high (IAF + 2 Hz) entrainment frequency for presenting auditory stimuli. These results demonstrate that sensory entrainment in the alpha range influences behavioral performance and temporal resolution of perception in particular.

Related results were demonstrated by de Graaf et al. (2013). They provided rhythmic cues that were presented visually, which resulted in oscillatory patterns in behavioral performance measures. The authors also showed that this pattern is linked to individual resting state alpha oscillations as obtained by MEG measurements.

That the entrainment of neural oscillation can be achieved by presenting visual stimuli has also been demonstrated by Mathewson et al. (2012). That study reported an effect of rhythmic entrainment in the behavioral response pattern which depends on the power of spontaneous alpha activity before the experiment. Crucially, this effect can be interpreted as an influence of visual entrainment on temporal attention and explained as a mechanism of optimization in the visual system, so that temporally predictible events can be processed best (e.g., Schroeder & Lakatos, 2009). The authors included another experimental manipulation in their setup, multiple different phase offsets for the target. They could demonstrate that the best performance in detection could be achieved if the target was presented in phase with the rythmic entrainment, and that the performance was worst for targets presented out of phase. Two different phase offsets were also used in the present study to replicate these findings.

Mathewson et al. (2009) could show that the extent, to which the masking of the target is counteracted by rhythmic entrainment, depends on how many entrainer stimuli were presented. While the authors used 2, 4 and 8 entrainers, the present study used 10 entrainers for both frequency conditions within the alpha range to ensure a comparable strength of entrainment.

The usual approach to examine the effect of individual alpha frequencies is usually to characterize them by their power distribution or the phase of the oscillations at a certain time (Kizuk & Mathewson, 2017). The present study aims to explore a different approach, based on the most prevalent frequency in the alpha range. The main thought for this apporach is based on the properties of oscillations: A higher frequency is a result of faster oscillating activity. Klimesch, Doppelmayr, Schimke, & Pachinger (1996) already adress this in their discussion. They also present data that link interindividual differences in IAF to differences in reaction times. Hence, a higher alpha frequency could indicate faster processes in the visual system, which in turn could have an effect on the performance of participants in certain tasks.

To explore this, an experimental design related to the experiments done by Mathewson et al. (2012) and Mathewson et al. (2009) was used. As an additional novel manipulation, the entrainment frequency of the stimuli preceeding the target stimulus was varied to include a high and a low frequency within the alpha region, 8 Hz and 12 Hz, and an additional control condition outside of the alpha region, 30 Hz. A crucial difference are the stimuli that were used: While Mathewson et al. (2009) and Mathewson et al. (2012) used disk stimuli and a metacontrast masking paradigm, the present study used stimuli based on straight lines, as in the experiment in the first section of this study. The main hypothesis is that entrainment to higher frequencies within the alpha range (12 Hz) results in higher performance than for lower frequencies within the alpha band (8 Hz). Outside of the alpha range, no entrainment effect on the performance should be evident (30 Hz).

3.2 Methods

The following sections describe the experiment conducted for this study. The goal was to experimentally entrain different frequencies and to check if these visually entrained frequencies influenced the participants' performance in a near-threshold stimulus discrimination task, using behavioral measures and EEG.

3.2.1 Participants

Twenty-four naïve volunteers (twelve female, twelve male; mean age 24.6 years; range 18 - 30 years) participated in this experiment. All subjects had normal or corrected-to-normal vision (visual acuity range 1.0 - 2.32), tested with the Freiburg Visual Acuity and Contrast Test FrACT (Bach, 2006). Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971, see Fig. A.1), which classified three participants as left-handed (using the score 20 as a boundary; this resulted in one participant being classified as right-handed, score 23.8, in contrast to this person's self-evaluation). Subjects were compensated with money (12€ per hour) or course credits. To increase motivation of all participants, the best five subjects (in terms of their performance) additionally could receive a voucher (10€).

3.2.2 Data acquisition and experimental procedure

Data acquisition (EEG and behavioral) occurred in the same electromagnetically isolated, soundproof chamber used in the experiment of part one (see section 2.2.2) that was only illuminated by the monitor. Each subject participated in three experimental blocks that were recorded separately: resting state recording '*pre-experiment*' (1), experimental task (2), resting state recording '*post-experiment*' (3). For exploratory measures, participants afterwards filled in a short questionnaire (see Appendix, Fig. A.4 and Fig. A.5).

Acquisiton of EEG data. EEG data was acquired with the same configuration as in the experiment in the first part of this study, see section 2.2.2 for details.

Resting state (1, 3). For both resting state EEG-recordings, participants were asked to sit calmly with their eyes closed. Recording started after the door was closed and visual inspection of on-line EEG data indicated no major eye movement and closed eyes. Subjects were asked not to keep track of the time by counting but to wait and relax for two minutes, until the experimenter stopped the recording and opened the door to the recording booth again.

Experimental task (2). After a general description of the task (see Appendix, Fig. A.6), subjects were presented with an 'easy' demonstration of the task (longer presentation of target stimuli, 83 ms) to get familiar with the presentation and look of the stimuli, and to get used to the expected reactions. For this, the eight random trials in the demonstration block were repeated, until all responses were correct.

After this, subjects completed a practice block with the same timing of the stimuli as in the experiment itself (8.3 ms), consisting of 16 random trials. During both of these blocks (demonstration and practice block), the experimenter was present and encouraged the participant to provide fast answers. Depending on the participants' performance and feedback, they were assured of the existence of the target stimuli and provided with details on the stimulus presentation of the different trial types (entrainment condition, called 'the flickering sequence' or control condition, called 'a kind of pause between two stimuli') to ensure correct understanding of the task. The trials were repeated until the participant responded in time for each of these practice trials

After the practice block, participants were reminded to react as fast possible and encouraged to answer intuitively only if they did not see a target. To motivate them to answer as correct as possible, they were informed that they could win a voucher (value 10€) if they were amongst the five best participants, which they could achieve by 'reacting as correctly and as fast as possible'.

Then the experimental task started; it took 35 - 45 minutes and was split into 9 experimental blocks with 48 trials each, resulting in 432 trials in total. Subjects had longer breaks after the third and sixth block, where the recording booth was opened to check on the participants. In the shorter breaks between the experimental blocks, participants were instructed to close their eyes for a moment and to continue the experimental task at their own pace by the presentation of according instructions on the screen.

3.2.3 Stimuli and trial structure

The stimuli were presented using the same configuration (monitor, software) as in the experiment described in the first part of this study, see section 2.2.4 for details. Participants were instructed to only use their left and right index fingers to react with the left and right button. For details on the specifications of the stimuli used (fixation cross, mask, target) see section 2.2.4.

The task was to discriminate between parallel horizontal and vertical lines presented as a target stimulus for 8.3 ms (see Figure 5). The assigned button was balanced between participants, so half of the participants had to press the right button for horizontal lines, the other half had to press the left button. All stimuli were presented in white on black background.

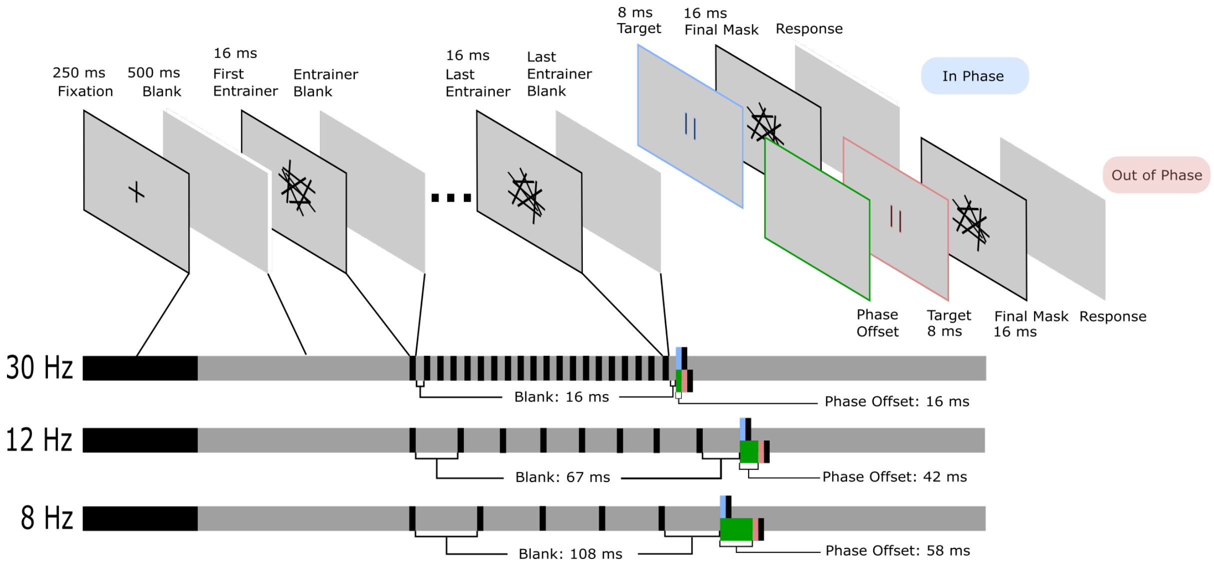

Figure 5: Schematic trial structure. Participants attended a central cross which dissappears, the entrainment phase starts after a fixed delay: Randomized entrainer stimuli were shown for 2 frames (16 ms) and alternated with blank screens of different durations. To ensure approximately constant trial lengths, twice as many entrainers and entrainer blanks were shown in the 30 Hz condition as in the 8 Hz or 12 Hz condition. In control trials, only the first entrainer and the final mask after the target were shown. For both the entrainer condition and the control condition, half of the trials included a blank phase offset, which was the closest duration to half of one entrainer blank that was possible with the screen's refresh rate. For the other half, the duration between the last entrainer and the target was identical to the duration between every two entrainers in the entrainment phase. Participants had to react to the horizontal or vertical masked target. After a maximum reaction time of one second a short warning popped up and ended the trial. All trials were the same length, regardless of the experimental conditions.

Each trial began with a central fixation cross presented for 249 ms and a 124.5 ms blank screen. After that, the first entrainer was presented for 16.6 ms, which consisted of thirty lines randomly placed in the center. To create a flickering stimulus in the entrainment trials, the entrainers alternated with a blank screen. Every entrainer was separately randomized to prevent visual learning of the masking stimulus. Depending on the frequency condition (8, 12 or 30 Hz), the entrainer blank was presented for 16.6 ms, 66.4 ms or 107.9 ms. For the 8 Hz and 12 Hz condition, ten entrainers were presented; to keep all trials approximately the same length, 20 entrainer masks were shown in the 30 Hz condition. This provided a minimal duration of entrainment of 664 ms in the 30 Hz condition, a medium duration for the 12 Hz condition (830 ms) and a maximal duration of 1245 ms for the 8 Hz condition.

As an additional condition a phase offset was introduced in half of the trials to check and replicate the behavioral findings of Mathewson et al. (2012), who showed a maximal detection performance at in-phase target presentations and minimal performance at ouf-of-phase presentations. For in-phase trials, the last entrainer blank had the same duration as the entrainer blank before it. To create maximal phase offset, additional blanks were shown in the out-of-phase condition so that the total duration of the blank before the target was at least 1.5 times the duration of the entrainer blanks in this trial. This resulted in phase offset blank durations of 16.6 ms, 41.5 ms or 58.1 ms for the 30 Hz, 12 Hz and 8 Hz conditions, respectively.

The target was always presented for one frame (8.3 ms) and was directly followed by a masking stimulus that was shown for 16.6 ms. In the control condition, only the first entrainer and the final mask after the target stimulus were shown, while the other entrainers were replaced by blanks. This condition provided behavioral and EEG data for trials without visual entrainment, but with the same timing. Participants had at most 1000 ms to respond, starting with the onset of the final mask; reaction times below 200 ms were not allowed, since this mostly indicated a spontaneous button press without processing of the target stimulus at all. Trials with reaction times below 200 ms or above 1000 ms were repeated later in the experiment, resulting in a constant number of valid trials per participant. Invalid trials were followed by a short note that informed the participant to react faster; no other feedback was provided. Participants did not receive feedback whether their answer was correct. Intertrial intervals were calculated so that every valid trial had the same length.

In total, the balanced experimental design had 2 (control vs. entrainment) $\times$ 2 (in phase vs. out of phase presentation) $\times$ 3 (8 Hz vs. 12 Hz vs. 30 Hz) experimental conditions.

3.3 Results

The goal of this study was to introduce different entrainment frequencies as an experimentally manipulated factor and examine their influence on participants' performance in a near-threshold disrimination task. The first sections (3.3.1 - 3.3.3) examine the IAF measure and the dependence of the task performance on the entrainment frequencies in order to explore the main hypothesis mentioned above. The following sections (3.3.4 - 3.3.8) are exploratory analyses without *a priori* hypotheses, in order to further examine the acquired data.

3.3.1 Comparison of IAF determination methods

The analysis to check for differences between the 'peak' method and the center of mass method was repeated as in section 2.3.1. In this case, the Shapiro-Wilk test indicated a significant deviation of the differences from normality, $W(24) = 0.82$, $p < .01$. In order to test the difference between the IAF values obtained by the peak method ($M = 10.28$, $SD = 1.12$) and the center of mass method ($M = 10.14$, $SD = 0.72$) for each participant, an exact Wilcoxon signed rank test was applied, which indicated that no significant difference between the two methods was evident, $W = 109.5$, $p = .31$. So as in part one, the following analyses will use the IAF values as calculated by the center of mass method.

3.3.2 Performance in entrainment condition

According to the hypotheses mentioned above, the presentation of a higher frequency entrainment (12 Hz) should result in a higher performance than in the trials with a lower entrainment frequency (8 Hz).

This effect should only be present in the alpha range, so the performance should not be higher in the 30 Hz condition than in the lower frequency conditions. Additionally, to replicate the findings of Mathewson et al. (2012), the in-phase target discrimination performance should be higher than the out-of-phase target discrimination performance.

For the performance data in the entrainment condition, a repeated measures analysis of variance (ANOVA) with the entrainment frequency (8 Hz, 12 Hz, 30 Hz) and presentation of the target stimulus (in phase, out of phase) as the independent variables was conducted. No main effects of frequency, $F(2, 46) = 1.24$, $p = .30$, or phase, $F(1, 23) = 0.03$, $p = .87$, were found on the task performance, and no interaction effect between these two factors was evident ($F(2, 46) = 0.27$, $p = .77$), see also Fig. 6.

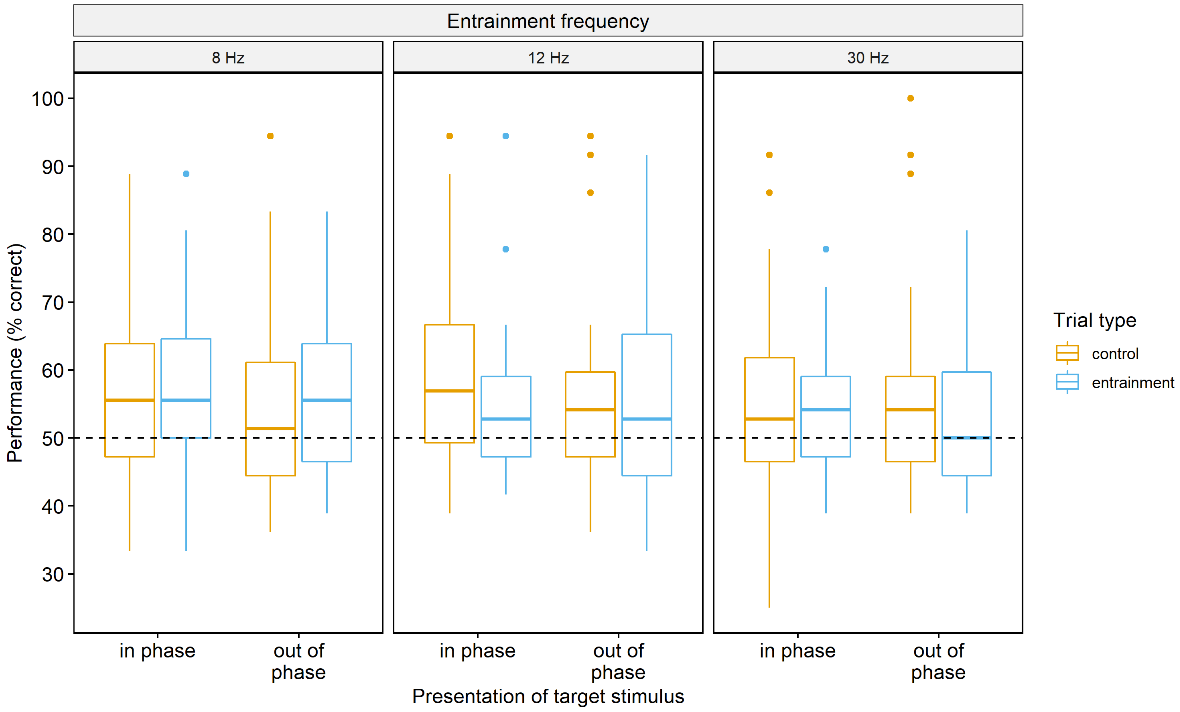

Figure 6: Summary of performance data. No significant main effects of frequency or target presentation could be found in both the entrainment and control trials. No interaction effects were evident. The dashed line indicates chance level.

3.3.3 Performance in control condition

For the control trials, no performance differences should be found between all conditions, since no entrainment happened. In consequence, the trials only differ in the amount of time between the first mask and the target stimulus (dependent on number of masks and the frequency as well as on the in-phase or out-of-phase target presentation, see Fig. 5), which overall should not have an effect on the performance.

As expected, a repeated measures ANOVA revealed no difference in performances between the 8 Hz, 12 Hz and 30 Hz condtitions in the control trials, regardless of the variables frequency ($F(2, 46) = 2.07$, $p = .14$) and target presentation ($F(1, 23) = 0.87$, $p = .36$). No interaction effect between these factors was found ($F(2, 46) = 1.73$, $p = .19$), see Fig. 6.

3.3.4 Exploratory analysis: Reaction times

An exploratory analysis of the reaction times, as indicated in section 3.3.8, was conducted. Following these reports of the participants, the reaction times for the control trials were expected to be slightly higher than for the entrainment trials.

A repeated measures ANOVA with the independent variables entrainment frequency, target presentation and trial type was conducted (see Fig. 7). Mauchly's test indicated a violation of the assumption of sphericity for the effect of frequency ($W = 0.59$, $p = .003$), so the affected degrees of freedom were corrected by using the Greenhouse-Geisser estimate of sphericity ($\varepsilon = 0.71$). The expected reaction time difference resulted in a main effect of trial type (entrainment, control) which approached significance ($F(1, 23) = 3.62$, $p = .07$), as did the interaction effect between trial type and phase ($F(1, 23) = 3.79$, $p = .06$). No further effects were evident.

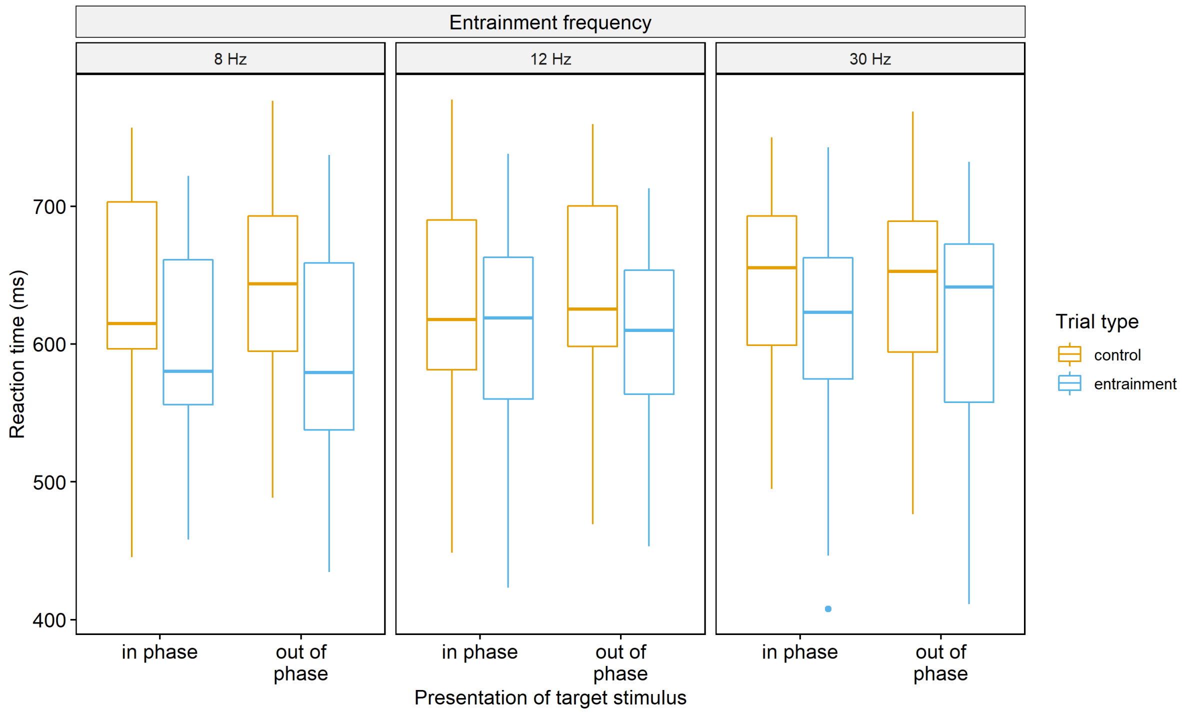

Figure 7: Summary of reaction time data. The reaction times for the entrainment trials were consistently smaller than for the control trials. No other effects were evident.

3.3.5 Exploratory analysis: Pre-experiment IAF and performance

As in part one of this study, additional examination of the connection between the individual alpha frequencies of the participants and their performance in this experiment should be adressed. Participants with a higher IAF should perform better than participants with a lower IAF. This effect should only be evident in the alpha range, so between both groups of participants no difference in performance should be observable in the 30 Hz entrainment condition. To test this hypothesis, the effects of target presentation (in phase, out of phase) and the control condition (no entrainment shown) should be neglected, since both are control conditions and could potentially shift the performance measure towards the chance level, obscuring a present effect.

For this, the participants were grouped according to their individual alpha frequency values as determined by the resting state recordings before the experiment. Four groups were formed, low alpha frequency (LAF), medium low alpha frequency (MLAF), medium high alpha frequency (MHAF) and high alpha frequency (HAF), each consisting of 6 participants (see Tab. 1).

IAF group	minimal IAF (Hz)	maximal IAF (Hz)	**mean IAF (Hz)**
LAF	8.5	9.9	9.1
MLAF	10.0	10.3	10.1
MHAF	10.3	10.5	10.4
HAF	10.5	11.5	10.9

Table 1: Classification into IAF groups, according to pre-experiment IAF. Note that all groups have the same size ($n = 6$), and the groups were defined by sorting the subjects' IAF values.

A mixed models ANOVA was then conducted on the performance data (only entrainment trials with the target presented in phase) with the within subjects factor being the entrainment frequency (8 Hz, 12 Hz, 30 Hz) and the between subjects factor being the assigned IAF group (LAF, MLAF, MHAF, HAF), see Fig. 8. As expected, a significant main effect of the IAF group could be observed ($F(3, 20) = 4.82$, $p = .01$). No main effect of frequency was evident. The interaction effect between frequency and IAF group approached significance, $F(6, 40) = 2.3$, $p = .05$, which explains the absence of a group effect in the 30 Hz condition. Post hoc pairwise comparisons grouped within the entrainment frequency conditions using the Tukey HSD test (Honestly Significant Difference, corrected p values for a family of four estimates within each entrainment frequency condition) showed a better performance of the MHAF group than the LAF group in the 8 Hz condition by 24.1% ($p = .001$) and a better performance than the MLAF group by 20.8% ($p = .006$). In the 12 Hz condition, the MHAF group had a significantly higher performance than the LAF group ($d = 17.1\%$, $p = .03$), MLAF group ($d = 15.7\%$, $p = .05$) and HAF group ($d = 17.6\%$, $p = .03$), respectively. In the 30 Hz condition, all four groups had a similar performance, and no further effects were significant.

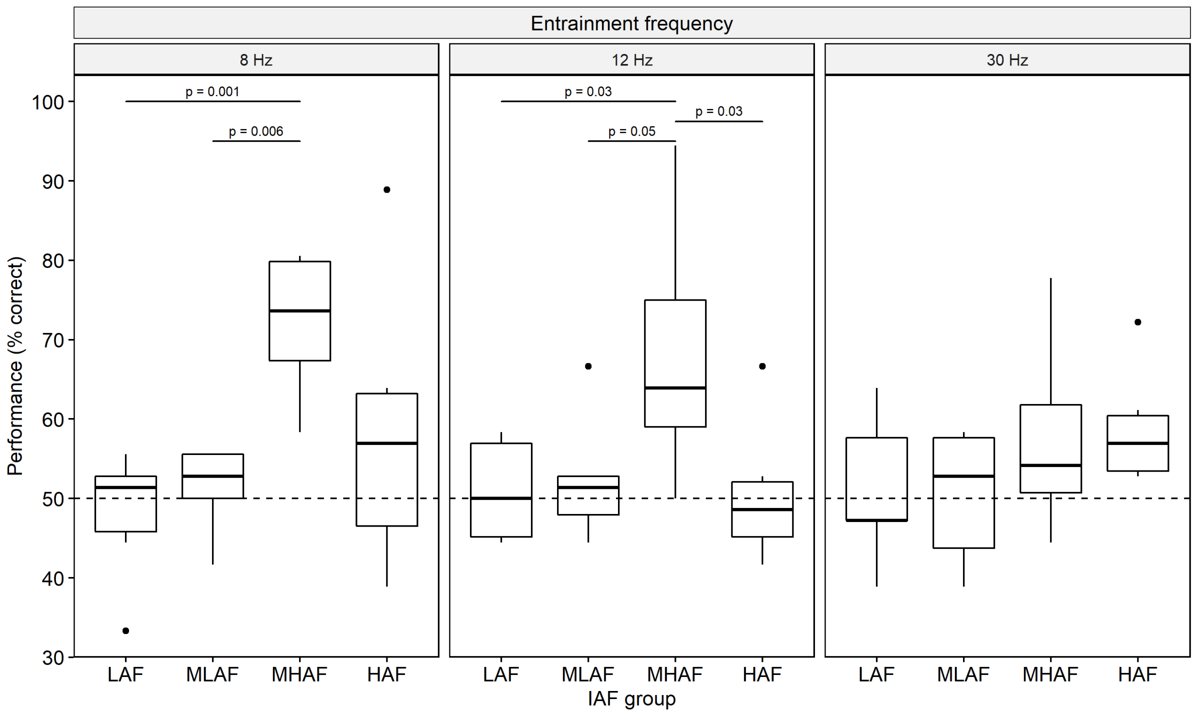

Figure 8: Pre-experiment IAF and performance in entrainment trials. The MHAF group reliably scored higher than the LAF group and the MLAF group in the entrainment consitions for 8 Hz and 12 Hz (within the alpha frequency band). All four groups had a similar performance in the 30 Hz condition.

3.3.6 Exploratory analysis: Post-experiment IAF and performance

As suggested above, the individual alpha frequency underlies a variability, which includes (amongst others), the influence by performing a cognitively demanding task. The following analysis investigates the connection between the IAF value as determined *after* the experiment and the task performance.

As above, all participants were sorted into four groups (LAF, MLAF, MHAF, HAF) according to their IAF value after the experiment. Since the amount of subjects per group was kept the same as before ($n = 6$), it is possible that participants were now in different groups than in the classification in section 3.3.5, see also Tab. 2. For more details on the change of IAF for each participant, see section 3.3.7.

IAF group	minimal IAF (Hz)	maximal IAF (Hz)	**mean IAF (Hz)**
LAF	8.7	9.5	9.0
MLAF	9.6	10.1	9.9
MHAF	10.1	10.5	10.3
HAF	10.5	11.4	10.6

Table 2: Classification into IAF groups, according to post-experiment IAF. Note that all groups have the same size ($n = 6$), and the groups were defined by sorting the subjects' IAF values.

A mixed models ANOVA with the IAF group as between-subjects factor and the entrainment frequency as the within-subjects factor was conducted on the performance data (only entrainment trials, target presentation in phase), see Fig. 9. In contrast to the findings in section 3.3.5, no significant main effect of IAF group ($F(3, 20) = 1.48$, $p = .25$) or frequency ($F(2, 40) = 2.4$, $p = .10$) was evident, and no interaction effect was found ($F(6, 40) = 1.83$, $p = .12$).

Visual inspection of the data in Fig. 9 indicates a tendency of better performance for the HAF group in the 8 Hz and 12 Hz entrainment conditions.

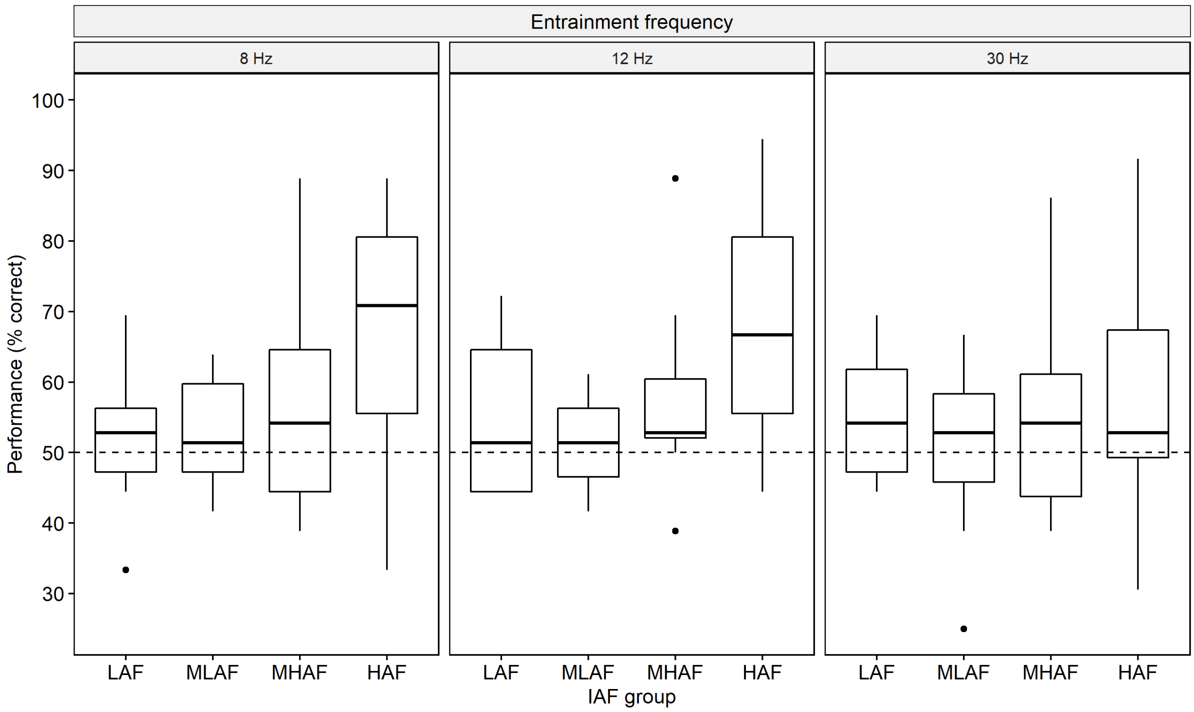

Figure 9: Post-experiment IAF and performance in entrainment trials. No statistically significant effects were evident.

3.3.7 Exploratory analysis: Comparison of pre-experiment and post-experiment IAF

As can be seen in Fig. 10, most participants' IAF did not show a large difference between the pre-experimental and the post-experimental recording, which translates to a high reliability for the IAF as an interindividual measure ($\rho_p = 0.9$, $p < .001$). Nevertheless, visual inspection shows that most participants had a slightly lower IAF after the experiment.

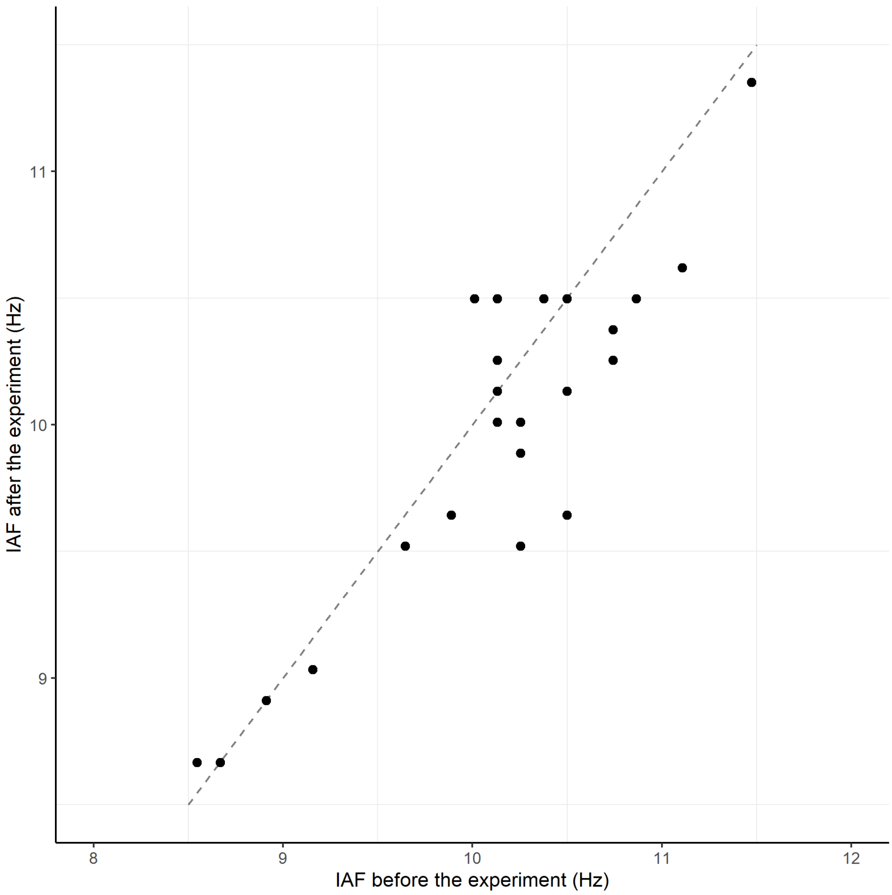

Figure 10: Comparison of pre- and post-experiment IAF. The dashed line indicates identity between the two measures. Most participants are located slightly below this line, which means their IAF value is lower after the experiment.

3.3.8 Exploratory analysis: Questionnaire

Participants filled in a short questionnaire after the experiment, see Figs. A.4 and A.5. The following section gives an overview over the answers provided, but no further analysis was done on these answers, also due to the open nature of the questions.

Strategies to handle the task varied between participants. Very few participants answered to have reacted randomly or according to their 'gut feeling'. Some participants used the fixation cross or the entrainer stimuli to shift their attention to a location not directly in the center or 'defocussed' the screen. Roughly the same amount of participants answered that they looked only for horizontal or vertical lines and pressed the according button only if they saw these lines; if they did not see what they were looking for, they answered with the other button.

Half of the participants noted that the control condition (no entrainment) was harder, since they did not exactly know when they could answer and thus sometimes missed to react in time. This could be the explanation that reaction times for the control trials are higher than for the entrainment trials (see section 3.3.4). On the other hand, a quarter of the participants indicated that the control condition was easier, since no flickering stimuli were presented, which were experienced as exhausting to the eyes.

Roughly half of the participants answered that they did not come in contact with fast flickering images very often. The other participants indicated that they did come into contact to flickering images mostly via television or computer screens.

The self-evaluated performance measure was in the range of 5 - 85 %, with the majority of the participants indicating a value around 40 - 60 %.

3.4 Discussion

The goal of this experiment was to explore the influence of visually entrained frequencies in the alpha range on the performance of subjects in a near-threshold stimulus discrimination task. In order to do so, the IAF determination method was explored. Then the performance of the participants in the entrainment or control trials was examined, yielding no significant effects. An exploratory analysis of reaction times showed faster reactions for entrainment trials, which could be explained by evaluating the participants' answers to the post-experimental questionnaire. Further exploratory analyses took into account the dependence of the performance on the pre- and post-experimental individual alpha frequencies, which was followed by a comparison of these two measures.

As in part one of this study, it has been shown that the center of mass method results in similar values as the peak method to calculate the IAF values. This supports the idea that IAF values are valid interindividual markers of neural activity.

In contrast to the findings of Mathewson et al. (2009) and Mathewson et al. (2012), no difference in performance could be found between the in phase and out of phase presentation of the target stimulus. This could be the result of the different stimuli used in the present study, which seem to be more complex and thus could interact with the effect of the entrainment on the performance. There was also no significant difference in performance between the entrainment and the control condition, which could be explained by the same interaction. The main hypothesis of this section of this study, that the entrainment frequency has an effect on the task performance, cannot be supported by the acquired data.

However, exploratory analyses indicate that the pre-experimental IAF measures could predict the performance of the participants. If this is indeed an effect of the individual alpha frequencies or an artifact of, e.g., the group classification, needs to be further examined, especially since only the medium-high IAF group showed a significantly higher performance in the entrainment conditions within the alpha range. If the line of reasoning followed by this study was correct, the high IAF group should also have scored a higher performance value.

Regarding the post-experimental IAF measures, no statistically significant effect could be found, yet visual inspection indicates a higher performance for the high IAF group. Whether the higher IAF caused the better performance or subjects with a better performance shift their IAF during the experiment to a greater extent than other subjects, cannot be inferred.

The reliability of the IAF measure before and after the experiment is high, only a slight tendency of subjects lowering their IAF in the course of time could be observed. Whether this tendency is a result of the experimental task or a general tendency, has not been examined here.

The present study did not show that visual entrainment to different frequencies does influence participants' performance. Further studies are required to examine this result in detail, especially adressing the kind of stimulus used during the experiment and using EEG measures to check if visual entrainment has an effect on ongoing alpha oscillations during the task. The latter has not been a part of this study but could potentially explain the absence of an effect, if no influence on alpha oscillations can be demonstrated.

4 Conclusion

In combination, the two sections of this study do not represent strong evidence that IAF has predictive value for the performance of participants in tasks like the ones presented above. Although this could be an effect of the kind of stimuli that were used, no final conclusion can be drawn from these results. Indeed, IAF has been demonstrated to be a predictor of visual evoked potentials (Koch et al., 2008), reaction times (Klimesch et al., 1996) and the effect of frequency-specific flicker on stimulus processing (Gulbinaite et al., 2017).

If interindividual differences in processing near-threshold stimuli can be predicted by IAF measures could not be answered in this study. Exploratory analyses did show a tendency of higher performance being linked to higher individual alpha frequencies, but the present experiment did not result in clear effects.

The results presented were acquired under the assumption that individual alpha frequencies could be an indicator of internal visual processes and especially their speed. Providing a measure for interindividual speed differences in visual perception or temporal resolution of the visual system could explain several phenomena (perception of illusory flicker, e.g., Minami & Amano, 2017; attentional blink, e.g., Zauner et al., 2012; rhythmic stimuli counteracting visual masking, e.g., Mathewson et al., 2009), but to what extent individual alpha frequencies and their characteristics can explain them, remains to be seen.

Rhythmic visual entrainment and its effects on visual processing and perception still provide many questions to be answered. Especially the experimental designs to examine these effects need to be established, as well as a consensus on how to quantify the different characteristics of individual alpha frequencies; this would provide more options to compare results across different studies.

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6 Appendix

eeg1907

Edinburgh Handedness Inventory

Teilnehmer-ID: ___________________________________
Datum: ___________________________________

Bitte markieren Sie bei den jeweiligen Tätigkeiten welche Hand Sie bevorzugt benutzen mit einem " + ". Bei den Tätigkeiten, bei denen die Präferenz so groß ist, dass Sie niemals versuchen würden, die andere Hand zu benutzen, außer Sie würden dazu gezwungen, schreiben Sie bitte ein " ++ " in das entsprechende Feld. Falls Sie sich nicht entscheiden können, tragen Sie bitte ein " + " in beide Felder ein, links und rechts.

Für manche Tätigkeiten werden beide Hände benötigt. In diesem Fall wird der Aufgabenteil oder das Objekt, für welches eine Bevorzugung der Hand verlangt ist, in Klammern angezeigt.

Bitte versuchen Sie alle Fragen zu beantworten und lassen Sie das Feld frei, wenn Sie keine Erfahrung mit einem Objekt oder einer Aufgabe haben.

	Links	Rechts
Schreiben		
Zeichnen		
Werfen		
Schneiden mit einer Schere		
Zahnbürste (Zähne putzen)		
Schneiden mit einem Messer (ohne Gabel); z.B. schnitzen		
Löffel		
Besen – welche Hand ist die Obere, wenn Sie kehren?		
Streichholz anzünden – in welcher Hand halten Sie das Streichholz?		
Schachtel öffnen – mit welcher Hand nehmen Sie den Deckel ab?		
Mit welchem Fuß kicken Sie (z.B. Fußball)?		
Welches Auge verwenden Sie, wenn Sie nur eines benutzen (z.B. Fotografieren)?		

Figure A.1: Handedness inventory. The same questions have been used for both experiments mentioned in part one and part two of this study.

Slide 1:

AUFGABE I

Das Experiment besteht aus zwei Aufgaben.

Die erste Aufgabe ist eine Reaktionszeitaufgabe.

Bitte verwenden Sie während des gesamten Experimentes

die LINKE Taste (grün) mit Ihrem LINKEN Zeigefinger und

die RECHTE Taste (rot) mit Ihrem RECHTEN Zeigefinger.

Bitte drücken Sie beide Tasten gleichzeitig um fortzufahren.

Slide 2:

INSTRUKTION

Im Folgenden erscheinen auf dem Bildschirm

zwei parallele Linien in horizontaler (=) oder vertikaler (||) Ausrichtung.

Ihre Aufgabe besteht darin,

mit dem Drücken einer Taste auf die Ausrichtung der Linien zu reagieren.

Bitte druecken Sie beide Tasten gleichzeitig um fortzufahren.

Slide 3:

Auf dem Bildschirm erscheinen zwei parallele Linien in horizontaler oder vertikaler Ausrichtung.

Ihre Aufgabe ist es:

bei VERTIKALER (||) [HORIZONTALER (=)] Ausrichtung die RECHTE Taste zu druecken,

bei HORIZONTALER (=) [VERTIKALER (||)] Ausrichtung die LINKE Taste zu druecken,

Bitte betaetigen Sie die korrekte Taste so schnell wie möglich.

Bitte druecken Sie beide Tasten gleichzeitig um fortzufahren

Figure A.2: Instructions for the '*indirect task*'. The content in square brackets depended on the group the participant was assigned before the experiment.

Slide 1:

AUFGABE II

Die zweite Aufgabe ist etwas schwieriger.

Bitte lassen Sie sich von Ihrem Gefühl, falsch zu reagieren, nicht entmutigen.

Bitte verwenden Sie während des gesamten Experimentes

die LINKE Taste (grün) mit Ihrem LINKEN Zeigefinger und

die RECHTE Taste (rot) mit Ihrem RECHTEN Zeigefinger.

Bitte drücken Sie beide Tasten gleichzeitig um fortzufahren

Slide 2:

INSTRUKTION

In der letzten Aufgabe wurden mehrere

Objekte auf dem Bildschirm angezeigt:

Reiz 1: Mehrere Linien mit unterschiedlichen Ausrichtungen

Reiz 2: Zwei Vertikale (||) oder horizontale (=) parallele Linien

Reiz 3: Mehrere Linien mit unterschiedlichen Ausrichtungen

Reiz 4: Zwei Vertikale (||) oder horizontale (=) parallel Linien

Bei der ersten Aufgabe hatten Sie auf den letzten Reiz (Reiz 4) reagiert.

Die anderen Reize sind nur kurz dargeboten worden.

Bitte vergewissern Sie sich,

dass Sie den Unterschied zwischen Reiz 2 und Reiz 4 verstanden haben.

Bitte drücken Sie beide Tasten gleichzeitig um fortzufahren

Slide 3:

Im Folgenden sollen Sie nur noch auf Reiz 2 reagieren.

Ihre Aufgabe ist es:

bei Reiz 2 VERTIKALER (||) [HORIZONTALER (=)] Ausrichtung die LINKE Taste zu druecken

bei Reiz 2 HORIZONTALER (=) [VERTIKALER (||)] Ausrichtung die RECHTE Taste zu druecken

Beachten Sie bitte:

Bei dieser Aufgabe ist Genauigkeit wichtiger als Geschwindigkeit.

Da Reiz 2 schwer zu erkennen ist, raten Sie bitte so gut es geht.

Konzentrieren Sie sich bitte auf die Aufgabe und vertrauen Sie auf Ihr Gefuehl.

Bitte druecken Sie beide Tasten gleichzeitig um fortzufahren

Figure A.3: Instructions for the '*direct task*'. The content in square brackets depended on the group the participant was assigned before the experiment.

Datum: ______________________ **Teilnehmer-ID:** ___________

Abschließender Fragebogen eeg1907

Allgemein

1. **Ist Ihnen beim Durchführen des Experimentes irgendetwas besonderes aufgefallen? Oder gibt es sonst irgendetwas, das Sie uns gerne mitteilen möchten?**

1

Figure A.4: Post-experimental questionnaire, first page.

Datum: ______________________ **Teilnehmer-ID: ___________**

Zum Experiment

2. **Wie gut konnten Sie auf den Zielreiz (parallele Linien) reagieren? Schätzen Sie Ihre generelle Performance ein.**
   (in Prozent %: 0 = Ich habe den Reiz nie gesehen, 100 = Ich habe den Reiz immer gesehen)
   ___________________ %

3. **Haben Sie zum Lösen der Aufgabe eine bestimmte Strategie angewendet? (Wenn ja: bitte kurz beschreiben)**
   ____
   ____
   ____

4. **Hat die Stimuluspräsentation (Flackern, ‚Pause') sie beim Bearbeiten der Aufgabe gestört? Wenn ja, in welchem Ausmaß?**
   ____
   ____
   ____

5. **Schätzen Sie ein: Wie oft haben Sie im Schnitt mit schnell flackernden Bildern zu tun? (Vor allem Spiele am PC/TV, häufige Teilnahme an Reaktionszeitexperimenten, … – Details auf freie Zeile unten schreiben)**

Mehr als einmal am Tag	Einmal am Tag	Ein- bis dreimal in der Woche	seltener	nie

____

2

Figure A.5: Post-experimental questionnaire, second page.

Slide 1:

START

Dieses Experiment ist ein Reaktionszeitexperiment.

Bitte verwenden Sie während des gesamten Experimentes

die LINKE Taste (grün) mit Ihrem LINKEN Zeigefinger und

die RECHTE Taste (rot) mit Ihrem RECHTEN Zeigefinger.

Bitte drücken Sie beide Tasten gleichzeitig, um fortzufahren.

Slide 2:

INSTRUKTION

Im Folgenden erscheint auf dem Bildschirm eine Sequenz von Objekten

sowie im Anschluss zwei parallele Linien in horizontaler oder vertikaler Ausrichtung.

Ihre Aufgabe besteht darin, mit dem Drücken einer Taste auf die

Ausrichtung der parallelen Linien zu reagieren.

Bitte drücken Sie beide Tasten gleichzeitig, um fortzufahren.

Slide 3:

INSTRUKTION

Auf dem Bildschirm erscheinen zwei parallele Linien in horizontaler oder vertikaler Ausrichtung.

Ihre Aufgabe ist es:

bei HORIZONTALER [VERTIKALER] Ausrichtung die LINKE Taste zu drücken

bei VERTIKALER [HORIZONTALER] Ausrichtung die RECHTE Taste zu drücken

Bitte betätigen Sie die korrekte Taste so schnell wie möglich.

Bitte drücken Sie beide Tasten gleichzeitig, um fortzufahren.

Slide 4:

DEMONSTRATION

Es folgt eine vereinfachte Demonstration der Objekte, die im Experiment präsentiert werden.

Bitte achten Sie darauf, WANN die parallelen Linien angezeigt werden:

am Ende der Sequenz

ODER

nach der kurzen ´´Pause´´.

Figure A.6: Instructions presented before the experiment. The content in square brackets depended on the group the participant was assigned before the experiment. Note that for preparing the participants for the different trial conditions (entrainment present or no entrainment present), they were advised to watch the timing of the target stimuli during the presentation on the last slide.

7 Statement

Hiermit erkläre ich, dass ich diese Arbeit selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel genutzt habe, alle wörtlich oder oder sinngemäß aus anderen Werken übernommenen Aussagen als solche gekennzeichnet habe, die Arbeit weder vollständig noch in wesentlichen Teilen Gegenstand eines anderen Prüfungsverfahren gewesen ist und die Arbeit weder vollständig noch in wesentlichen Teilen bereits veröffentlicht ist, sowie dass das in Dateiform eingereichte Exemplar mit eingereichtem gebundenem Exemplar übereinstimmt.

Ich erkläre, dass ich die Richtlinien zur Sicherung guter wissenschaftlicher Praxis und zum Umgang mit wissenschaftlichem Fehlverhalten an der Eberhard-Karls-Universität beachtet habe.

Florian Friedrich - Tübingen, den 2.12.2019