U.PORTO

INTEGRATED MASTER'S IN PSYCHOLOGY
CLINICAL AND HEALTH PSYCHOLOGY

Exploring the psychophysiology of mantra meditation: Effects of repetitive speech on attention, autonomic control, and cortical entrainment

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M

2020

Universidade do Porto

Faculdade de Psicologia e de Ciências da Educação

EXPLORING THE PSYCHOPHYSIOLOGY OF MANTRA MEDITATION: EFFECTS OF REPETITIVE SPEECH ON ATTENTION, AUTONOMIC CONTROL, AND CORTICAL ENTRAINMENT

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June 2020

Dissertation submitted for the Integrated Master's Degree in Psychology, Faculty of Psychology and Educational Sciences of the University of Porto, supervised by Professora Doutora *São Luís Castro* (FPCEUP) and co-supervised by Doutora *Susana Silva* (FPCEUP).

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ACKNOWLEDGEMENTS

I am grateful to Professora Doutora São Luís Castro, for believing in this project from the very beginning, allowing it to take form, and for her guidance and conceptual and methodological direction. I am also grateful to Doutora Susana Silva, for the valuable ideas that have made this research a coherent whole, and for her methodological and technical advice.

I wish to thank Teresa Jacques, for her comitted instruction in ECG measurement and analysis. A word of thanks to the pilots and participants of this study, for their time and patience. I am thankful to my lab colleagues Svetlana and Rui for their advices, and to my faculty colleagues Rita, Maria, and Diogo, for the supporting words since the beginning of this work.

I am thankful to my family, and specially to my parents, for their continuous motivation and enthusiasm. I also wish to thank Daniel Cosme for lending his voice to the practice recordings, but above all for his day-to-day support and inspiration, that nurtured me over the time of this study.

Finally, I am grateful to the researchers who devote their time studying the effects of meditation in human health and to the many meditation and Yoga teachers who share a path of peace.

ABSTRACT

Repetitive speech has been proposed to be a fundamental component of mantra meditation, but little is still known about the neurocognitive mechanisms that it might involve. This study had two main objectives: to understand if repetitive speech with a mantra and repetitive speech with words would elicit the typical correlates of mantra meditation (increased attention and autonomic control) in a similar way; to test if repetitive speech would elicit cortical entrainment at the repetition frequency. Participants (*n* = 12) were asked to perform repetitive speech tasks in three conditions: mantra repeated at a rhythm of 0.2 Hz, word repeated at 0.2 Hz, and word repeated at 1 Hz. Behavioural and electrophysiological measures were obtained during an auditory oddball task as indices of attention, and heart rate was measured. Results indicate that both repetitive speech with a mantra and repetitive speech with words produced widespread decreased responsivity to non-target stimuli. The continuous and rhythmic repetition of non-mantra words is thus able to modulate attention, a result that adds to the evidence that repetitive speech is a relevant component of mantra meditation. On the other hand, autonomic control was not significantly affected by repetitive speech. Evidence of entrainment to the repetition frequency was also not found.

Keywords: mantra meditation, repetitive speech, attention, autonomic control, entrainment.

RESUMO

A fala repetida foi considerada como uma componente fundamental da meditação com mantras, mas muito permanece por saber acerca dos mecanismos neurocognitivos que poderá envolver. Este estudo teve dois objetivos principais: perceber se a fala repetida com um mantra e a fala repetida com palavras elicitaria os correlatos típicos da meditação com mantras (atenção e controlo autómico aumentados) de forma semelhante; testar se a fala repetida elicitaria *entrainment* cortical à frequência de repetição. Os participantes (n = 12) realizaram tarefas de fala repetida em três condições: mantra repetido a um ritmo de 0.2 Hz, palavra repetida a 0.2 Hz e palavra repetida a 1 Hz. Foram obtidas medidas comportamentais e eletrofisiológicas durante uma tarefa auditiva *oddball* como marcadores de atenção, e foi medido o ritmo cardíaco. Os resultados indicam que tanto a fala repetida com um mantra como a fala repetida com palavras levaram a uma redução generalizada da responsividade a estímulos não-alvo. A repetição contínua e rítmica de palavras não-mantra é, por isso, capaz de modular a atenção, um resultado que acrescenta à evidência de que a fala repetida é uma componente relevante da meditação com mantras. Por outro lado, o controlo autonómico não foi afetado significativamente pela fala repetida. Não foi também encontrada evidência de *entrainment* à frequência de repetição.

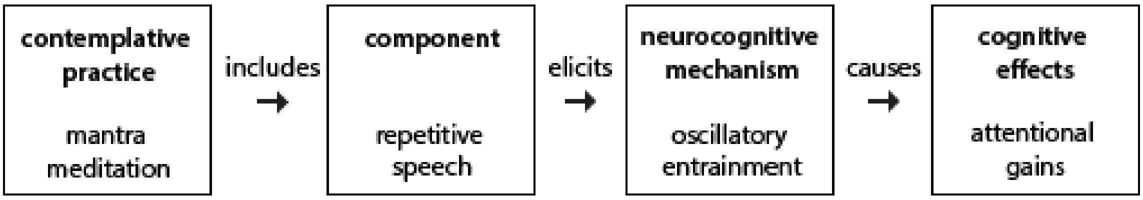
Palavras-Chave: meditação com mantras, fala repetida, atenção, controlo autonómico, *entrainment*.

1. Introduction

Although widely employed in various contemplative practices, meditation based on mantras is still lacking a scientific body of knowledge, and its neurocognitive mechanisms remain mostly unknown (Berkovich-Ohana et al., 2015). An operational definition of mantra meditation has not yet been proposed – one that allows testing hypotheses about its mechanisms and effects. In order to operationalize the concept of mantra meditation, its components must be clearly understood. Following Berkovich-Ohana et al., we start from the assumption that repetitive speech is a fundamental component of mantra meditation, and hypothesize that repetitive speech elicits oscillatory entrainment associated with attentional gains (see Figure 1). Results of this study might shed some light on the neurocognitive mechanisms of mantra meditation and encourage the use of repetitive speech as an experimental paradigm of mantra meditation.

Figure 1

Chain of concepts



1.1. Mantra meditation

Meditation has been defined as a range of emotional and attentional regulatory strategies aiming to cultivate well-being and emotional balance (Lutz et al., 2008). These practices can be organized into open monitoring meditation and focused attention (FA) meditation, according to the voluntary direction of attention (Lutz et al., 2008). In open monitoring practices, the content of experience is non-reactively monitored by attending to it without an explicit focus; the objective is to observe emotional and cognitive patterns. In FA practices, sustained attention is placed on a given object, with a narrow field of focus (e.g., the flow of breathing), and when attention wanders it must be returned back to the object. While open monitoring meditation creates an awareness of automatic reactions to stimuli, FA meditation improves the stability of sustained attention and the ability to detect mind wandering and disengage from distractors.

Meditation based on mantra recitation can be conceptualized as a FA practice, with the mantra being the object of sustained attention (Fox et al., 2016). Mantra recitation consists in the continuous silent or loud repetition of a verbal utterance, such as a sound, word or group of words (Berkovich-Ohana et al., 2015). The practice is included in several contemplative traditions (e.g., Transcendental Meditation, Kundalini Yoga) and is estimated to be practiced by around 31% of meditators (Vieten et al., 2018). A recent systematic review found evidence that mantra meditation positively impacts the mental health and affectivity of the general population, although more high-quality studies are needed (Lynch et al., 2018).

Meditative practices are associated with specific neurocognitive correlates, which are part of a meditation *state*, and also produce brain changes in the long-term, named as meditation *traits* (for reviews on meditation states and traits see: Cahn & Polich, 2006; Fox et al., 2014; Fox et al., 2016). A meta-analysis of neuroimaging studies with long-term practitioners (Fox et al., 2016) indicates that mantra meditation elicits neuronal activity in areas related to working memory and selective attention (posterior dorsolateral prefrontal cortex), motor behaviour and mental-operation tasks (left premotor cortex, presupplementary and supplementary motor cortices), visual word form processing (fusiform gyrus), and integration of information and mental imagery (cuneus and precuneus). It also produces neuronal deactivation in areas that receive nociceptive and viscerosensory input (left anterior insula/claustrum; Fox et al., 2016).

During mantra meditation, experienced meditators present increases in frontal midline theta (4 - 8 Hz) and frontal, parietal and occipital alpha (8 - 13 Hz) activity (Lee et al., 2018). Theta power gains across all brain regions are also observable in short mantra recitation sessions with non-meditators (Harne & Hiwale, 2018). While a stronger alpha rhythm is associated with relaxation and lower levels of anxiety, frontal midline theta power (with origin in the prefrontal cortex and in the anterior cingulate cortex) usually increases during sustained attention and autonomic control states (Cahn & Polich, 2006; Lee et al., 2018). Increased alpha coherence among brain areas during mantra meditation and increased theta coherence after training have also been reported (Lee et al., 2018). Experienced meditators present changes in mid- (Na, Pa, and Nb components) and long-latency (P2 component) auditory evoked potentials during mantra meditation, suggesting that it modifies neural generators in the thalamus, thalamic radiations, and primary auditory cortical areas (Singh & Telles, 2015).

Heart rate and heart rate variability (HRV) are typically used as biomarkers of autonomic regulation during meditation (e.g., Kubota et al., 2001; Tang et al., 2009). Heart rate consists in the mean frequency of heartbeats, while HRV measures the change in time intervals between heartbeats. The mantra meditation state is characterized by a lower heart rate, with an average decrease of 5 beats per minute during meditation (Wallace, 1970). Heart rate slowing is observed when the parasympathetic tone increases and the sympathetic tone decreases (Berntson et al., 2007). Increased high-frequency HRV power is also observed during mantra meditation (Travis, 2001). High-frequency HRV (also known as respiratory sinus arrhythmia) indexes parasympathetic cardiac control associated with respiration (Berntson et al., 2007). Increases in high-frequency HRV after meditation interventions are associated with frontal midline theta power gains, suggesting meditation-related control over parasympathetic activity (Tang et al., 2009).

1.2. Repetitive speech as a component of mantra meditation

During FA meditation, activation of the attention system reduces the default mode network (DMN) activity (Fox et al., 2016). The DMN (i.e., ventral and dorsal medial prefrontal cortex, posterior cingulate cortex, precuneus, inferior parietal lobule, lateral parietal cortex, lateral temporal cortex, and hippocampal formation) is generally associated with mind-wandering, emotional and self-referential processing, and recollection of past experiences (Buckner et al., 2008; Raichle, 2015). Contrarily to what would be expected, meta-analyses do not indicate deactivation of the DMN during mantra meditation (Fox et al., 2016).

Tipically, mantra meditation studies use a repetitive speech task as a control condition; for example, Engström et al. (2010) asked participants to continuously repeat the words "table and chairs". However, there is evidence that the use of a repetitive speech task as a control condition may impede observing significant deactivation in the DMN during mantra meditation. First, when compared to a finger-tapping control task, mantra meditation is seen to significantly deactivate various regions of the DMN (Simon et al., 2017). Second, Berkovich-Ohana et al. (2015) tested whether a repetitive speech task would be enough to produce a meditation state, by asking non-meditators to covertly and continuously repeat a single non-mantra word. Compared to resting state, the repetitive speech task was sufficient to inhibit DMN activity, suggesting that repetitive speech might be an important component of mantra meditation.

Repetitive speech can be defined as a process consisting of (1) the overt or covert speech production of (2) a phoneme, syllable, word or phrase, which is (3) continuously repeated in (4) a given pace. Repetitive speech seems to be able to induce a meditation state, indicating that the effects of mantra meditation might be due, at least partially, to the continuous, rhythmic repetition of an utterance which is the object of focused attention.

1.3. Entrainment to repetitive speech

Mantra recitation is produced rhythmically, which means that the mantra is repeated at a given frequency. An emerging hypothesis is that the rhythmic recitation of a mantra – i.e., repetitive speech – is capable of entraining brain oscillations to the frequency of the repetition. Entrainment of ongoing oscillations consists in the alignment of the temporal dynamics of neural processing to a rhythmic stream of stimuli (Calderone et al., 2014; Schroeder & Lakatos, 2009). When an external input has a predictable temporal structure, the brain functions in a rhythmic mode: as the attended salient stimulus is perceived, the phase of oscillations occurring at the same frequency as the stimuli stream is reset (Calderone et al., 2014). Simultaneously, the brain's rhythmic mode also suppresses inputs that are out of phase with the attended stream in order to become more efficient. Entrainment of brain oscillations has been proposed to subserve selective attention, since rhythmic, and therefore predictable, stimuli are more easily perceived and learned (Schroeder & Lakatos, 2009).

To our knowledge, no studies have yet tested the existence of cortical entrainment during a repetitive speech task (i.e., phase-locking of brain oscillations to the rhythm of repetitive speech). Entrainment to continuous speech is well documented, evidencing that auditory cortical activity (< 8 Hz) is entrained to the syllabic rhythm of speech (e.g., Ding & Simon, 2014; Zoefel & VanRullen, 2015). Entrainment to speech might have different functional roles, such as encoding speech relevant features (related to theta entrainment) and acoustic rhythm (related to delta entrainment; Ding & Simon, 2014). Importantly, the phase of delta and theta brain oscillations is aligned with the attended speech rhythm, suggesting that neural entrainment constitutes an input gating mechanism that improves speech intelligibility (Zoefel & VanRullen, 2015).

1.4. Aims and hypotheses of this study

1.4.1. Repetitive speech effects on attention and on autonomic control

The mantra meditation state typically shows gains in attention and autonomic control (Fox et al., 2016). The first aim of this study is to test if repetitive speech with a mantra (in Sanskrit) and repetitive speech with words in the native language (Portuguese) would elicit the expected electrophysiological correlates of mantra meditation in a similar way. Repetitive speech with a non-mantra word has been shown to elicit deactivation of the DMN (Berkovich-Ohana et al., 2015); however, there has been no further research on the effects of repetitive speech in other meditation biomarkers. Particularly interesting are the behavioural and neural markers of attention during a three-stimuli auditory oddball task, which has been extensively used to measure the neural effects of meditation, but – to our knowledge – has not yet been applied to mantra meditation. Using the oddball paradigm (see Method), meditation in general is associated with a reduction in responsivity to distractor stimuli (Cahn & Polich, 2009), and FA meditation increases responsivity to and reduces variability in the processing of target stimuli (Lutz et al., 2009; Telles et al., 2019). Thus, we hypothesize that repetititive speech with a mantra and repetitive speech with words will similarly elicit:

– H_A 1.1: improved behavioural markers of sustained attention; this will be indicated by increased sensitivity and reduced variability in response to target tones of an auditory oddball task;

– H_A 1.2: improved neural markers of sustained attention; this will be indexed by decreased neural response to distractor and standard tones and by increased response to target tones of an auditory oddball task;

– H_A 1.3: increased autonomic control, as indicated by a slower heart rate and increased high-frequency HRV.

1.4.2. Entrainment of brain oscillations during repetitive speech

The second aim of this study is to test whether a repetitive speech task elicits cortical entrainment to the frequency of repetitive speech, which will be at 0.2 Hz and 1 Hz (see

Method). This phenomenon is expected since entrainment to continuous speech and to rhythmical stimuli are well documented (e.g., Calderone et al., 2014). Our hypothesis (HA 2.1) is that, during each repetitive speech task, brain oscillations at the same frequency of repetitive speech will show increased phase coherence.

Oscillatory entrainment to rhythmic stimuli is an important attentional mechanism, which amplifies phase-locked relevant inputs and suppresses irrelevant ones (Schroeder & Lakatos, 2009). Continuously focusing on the repeated word during the repetitive speech task might strengthen attention, through the process of entrainment. Therefore, we will test if entrainment to repetitive speech is associated with increased attention after the task. Our hypothesis (HA 2.2) is that entrainment to the repetition frequency during repetitive speech correlates with electrophysiological indices of attention (i.e., neural response to the auditory oddball task stimuli).

2. Method

2.1. Participants

Sixteen participants[1] were recruited among Psychology students of FPCEUP. After data preprocessing, 4 of them were excluded due to noisy EEG signal. The final sample consisted in 12 women between 19 and 30 years of age (mean 21.0 ± 3.13 years), all right-handed. Seven participants had previously attended meditation classes/workshops, and three practiced meditation regularly (average years of practice 2.17 ± 1.43). No participant reported neurological or psychiatric conditions.

2.2. Procedure

All participants gave written informed consent to participate (Appendix A), and experimental procedures were approved by FPCEUP Ethics Committee (Ref. 2020/02-6b). The experiment was held in an acoustically shielded room, with a runtime of around 90 minutes (30 minutes for EEG preparation). In order to avoid expectations regarding personal performance in meditation (Davidson & Kaszniak, 2015), participants were told that the experiment included an attention task and a repetitive speech task. Participants sat comfortably at a desk. They had short breaks between tasks, during which they were offered water.

The experiment followed the sequence outlined in Figure 2. All participants carried out three repetitive speech tasks, whose order was counterbalanced. Before and after each repetitive speech task, participants were asked to remain still and with their eyes closed during 180 sec for heart rate measurement and, immediately after, to perform a three-stimuli auditory oddball task in a computer. Post-test measures of repetitive speech condition 1 were employed as pre-test measures of repetitive speech condition 2, and post-test measures of condition 2 were employed as pre-test measures of condition 3 (see Figure 2). Tasks, stimuli,

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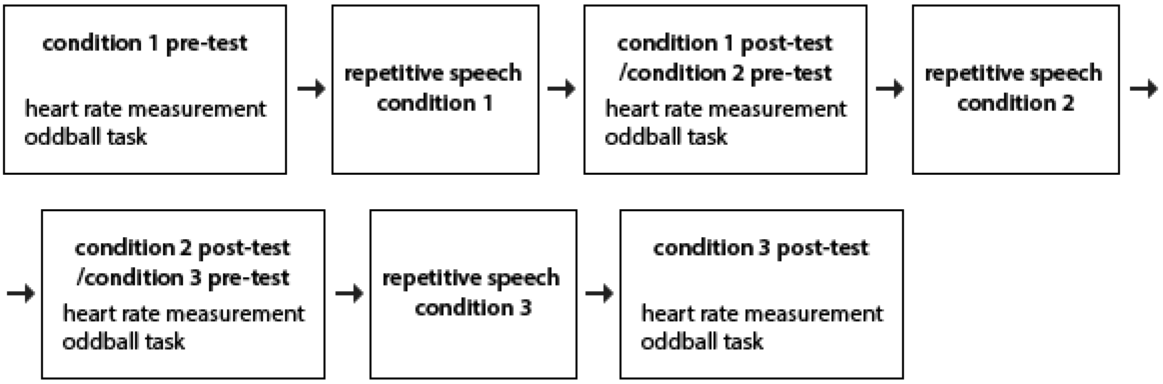
[1] Data collection was interrupted by the pandemic situation. Our original intention was to collect data from at least 33 participants in order to obtain a statistical power of 80% (power analysis performed in GPower [Erdfelder et al., 1996] for a repeated-measures ANOVA within factors with two measurements, with a medium effect size of partial $\eta^2 = .06$ and $\alpha = .05$).

and specific instructions were delivered via the program OpenSesame (Mathôt et al., 2012). At the end of the experiment, participants were debriefed about the research objectives.

Figure 2

Experimental sequence



2.3. Tasks and stimuli

2.3.1. Repetitive speech task

The frequency of mantra recitation is usually located in the delta-band frequency – i.e., one mantra uttered every 1-10 seconds, corresponding to a frequency from 1 to 0.1 Hz. Three repetitive speech conditions were designed to manipulate the factors utterance (mantra *vs*. word) and repetition frequency (0.2 Hz *vs*. 1 Hz): mantra repeated at 0.2 Hz rate (condition M0.2), word repeated at 0.2 Hz rate (condition W0.2) and word repeated at 1 Hz rate (condition W1). Conditions M0.2 and W0.2 were compared to test whether effects on attention and autonomic control would be similar after mantra repetition and words repetition. Conditions W0.2 and W1 were compared to test the existence of cortical entrainment at each repetitive speech frequency. Condition M0.2 consisted in the repetition of the mantra "om" – one of the most widely used mantras in various contemplative traditions (e.g., Transcendental Meditation, Kundalini Yoga) – once every 5 sec. Condition W0.2 consisted in the repetition of the utterance "agora são cinco" ("now it is five" in Portuguese) once every 5 sec. A short set of neutral words was chosen for condition W0.2 because having participants say several words would avoid an unnatural lengthening of only one word during 5 sec. Condition W1 consisted in the repetition of the word "sim" ("yes" in Portuguese) once every second. After pilot testing, we chose a short word that would be as less fatiguing to repeat as possible for the W1 condition, due to the high number of repetitions in this condition.

Instructions for the repetitive speech task consisted in maintaining the eyes closed, breathing normally, repeating the words aloud, and trying to focus attention on the repeated words. First, participants practiced the repetition pace of each condition by repeating the word(s)/mantra along with a recording. The practice recording was voiced by an experienced meditator. After practicing, participants were asked to continue repeating the word(s)/mantra at the pace they had just learned. Practice duration was 120 sec for 0.2 Hz conditions and 60 sec for the 1Hz condition, and experimental runtime was 120 sec for all conditions. We chose the repetitive speech runtime based on findings by Berkovich-Ohana et al. (2015), who reported a meditation-like state in non-meditators with 105 sec of repetitive speech. On average, participants were expected to produce around 24 word(s)/mantra repetitions in the 0.2 Hz conditions (plus 24 practice repetitions) and 120 word(s)/mantra repetitions in the 1 Hz condition (plus 60 practice repetitions).

2.3.2. Auditory oddball task

In a three-stimuli auditory oddball paradigm, participants are asked to respond to an infrequent target stimulus, while ignoring frequent standard stimuli and infrequent distractor stimuli (Polich, 2007). Two well-known event-related potential (ERP) components elicited in this task are the P3a component, in response to infrequent, task-irrelevant stimuli, and the P3b component (also known as P300), in response to infrequent, but task-relevant stimuli. Both components reflect the attentional process of updating the stimulus representation and working memory operations (Polich, 2007).

We adapted the procedure by Cahn et al. (2013). Each task consisted of 200 experimental trials preceded by 10 practice trials. The 200 stimuli were randomly presented for each participant, with a probability of 10% for targets, 10% for distractors and 80% for standards. Participants were told to press the spacebar, as quickly as possible, whenever they heard the target tone, and to ignore all other tones. Auditory stimuli were pure tones 60 ms long (10 ms of rise and fall time) with an intensity of 70 dB. Target tones consisted in 1000 Hz beeps, standards in 500 Hz beeps, and distractors in white noise bursts. A fixed interstimulus interval was set at 1300 ms, with a response timeout (i.e., available time for the participant to press the key) of 900 ms.

2.4. Electrophysiological data

2.4.1. Recording

EEG and ECG data were collected using a 64-channel (following the 10-20 system) Active-Two BioSemi system with a digitization rate of 512 Hz. Signal was referenced to the Common Mode Sense-Driven Right Leg BioSemi ground system. Following BioSemi signal quality guidelines, direct-current electrode offset was kept below ± 40 mV. External electrodes were placed at the right and left mastoids and below the left eye (electro-oculogram). For ECG recording, two external electrodes were placed at the left arm and at the left leg (bipolar lead III configuration; Berntson et al., 2007).

2.4.2. Preprocessing

EEG data preprocessing was based on the pipeline suggested by Luck (2014) and used the FieldTrip MATLAB toolbox (Oostenveld et al., 2011). Continuous EEG was bandpass filtered between 0.01 and 30 Hz and bad channels were identified by visual inspection and interpolated (maximum 5% of the channels). Independent components analysis (ICA) was used to remove components with blink and ECG artifacts based on their topography and time course. Data was re-referenced to the average of the mastoids. To obtain oddball task epochs, continuous data was epoched in single-trial segments from -700 to 1300 ms around the onset of each tone. Oddball task epochs were then visually inspected and trials with artifacts were rejected (*M* = 34.48, *range* = 0 - 74). To obtain repetitive speech epochs, continuous data were epoched between -2000 ms and 3000 ms around the onset of each word/mantra repetition and artifact rejection by visual inspection was performed.

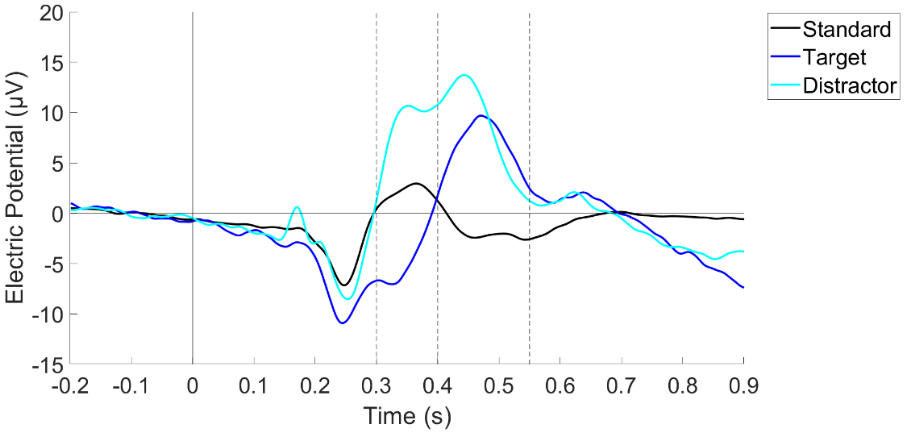
ECG raw data was bandpass filtered between 0.5 and 35 Hz to remove baseline drift and high-frequency noise (Ruha et al., 1997). Then, the left arm signal was subtracted from the left leg signal. Detection of R peaks and RR series correction (by visual inspection and interpolation of missing beats) were performed using the HRVanalysis software (Pichot et al., 2016).

2.4.3. Processing

2.4.3.1. Oddball task trials: Event-related potentials. ERP components P3a and P3b were measured to quantify the effects of repetitive speech on attention. First, oddball task single-trial EEG epochs were further cut from -200 to 900 ms, baseline corrected (baseline from -200 to 0 ms) and detrended. Trials were averaged for each subject according to stimulus type, with latency between -200 and 900 ms around the stimulus onset. The P3a component was measured in distractor trials by computing the mean amplitude (i.e., average voltage) from 300 to 550 ms for each channel (Luck, 2014). The P3b component was measured in target trials from 400 to 550 ms. These time windows were chosen in an unbiased fashion, based on visual inspection of average ERPs across all repetitive speech conditions (pre- and post-M0.2 and pre- and post-W0.2; see Figure 3) and on the typical latency of the P3 waves (Conroy & Polich, 2007; Lutz et al., 2009). Individual-channel mean voltages were finally averaged into nine Regions of Interest (ROIs; see Statistical Analysis).

Figure 3

Average ERP across all repetitive speech conditions in the Cz channel



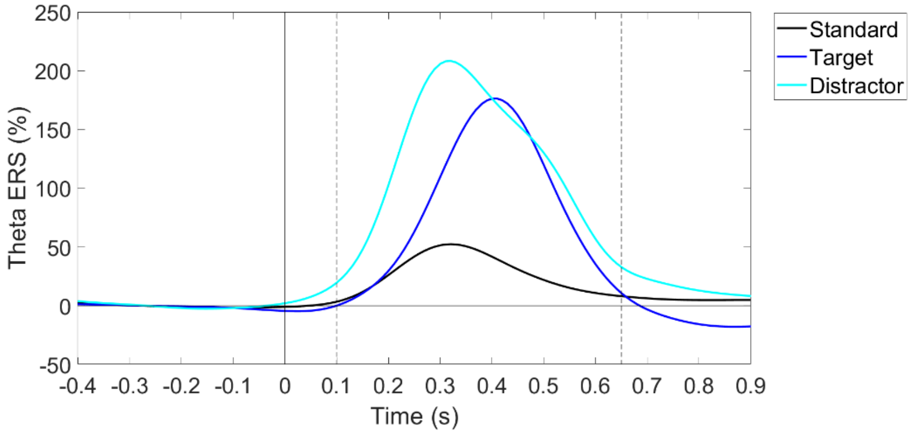
Note. The dashed lines indicate the two time windows where mean amplitudes were computed: 300-550 ms for P3a and 400-550 ms for P3b.

2.4.3.2. Oddball task trials: Event-related synchronization. Event-related synchronization (ERS) in the theta band during the oddball task was used as a measure of the effects of repetitive speech on attention. First, single-trial EEG epochs were subjected to time-frequency decomposition with a Hann taper and fixed window length (Oostenveld et al., 2011). Epochs had a latency from -700 to 1300 ms to include four full time windows of 500 ms (time of interest from -400 to 900 ms, plus buffer zones to avoid edge artifacts; Cohen, 2014). In fixed window length methods, the frequency resolution corresponds to 1/*length of time window* (sec), and an integer number of cycles must fit in the epoch time window. Therefore, a 500 ms time window was chosen to obtain a 2 Hz frequency resolution. Time-frequency decomposition was computed between -400 and 900 ms in steps of 10 ms, in each electrode. Power values (i.e., amplitude squared) were taken at 4, 6 and 8 Hz for each type of trial (i.e., target, standard and distractor).

The ERS is computed as a baseline normalization of the averaged power data (Cohen, 2014; Pfurtscheller & Lopes da Silva, 1999). First, power values were averaged across frequencies to obtain a single average value for the theta band. Power values for each timepoint were computed as *(A - R)/R * 100*, where A is the power for that timepoint and R is the average power in the baseline window from -400 to -100 ms. Individual channel ERS values were averaged into nine ROIs (see Statistical Analysis). Average ERS for each stimulus type were calculated as the mean percentage power change from 100 to 650 ms in relation to the baseline. This time-frequency window of interest was selected orthogonally to the condition comparisons, by visual inspection of ERS plot for the average of all repetitive speech conditions and all subjects (Cohen, 2014; Figure 4).

Figure 4

Average ERS across all repetitive speech conditions in the Cz channel



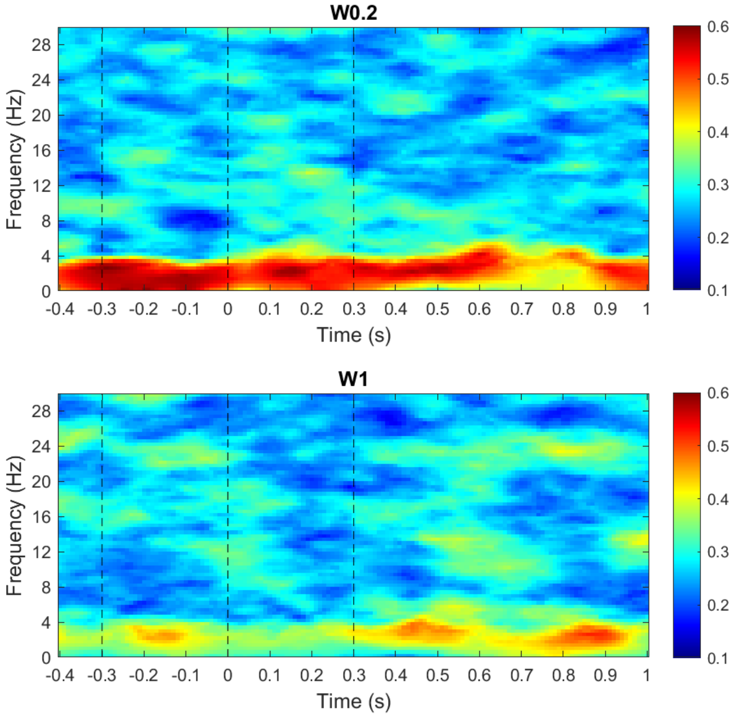
Note. The dashed lines indicate the time window where theta ERS was computed (100-650 ms).

2.4.3.3. Repetitive speech trials: Intertrial phase coherence. Intertrial phase coherence (ITPC) in repetitive speech trials was computed as an index of entrainment of neuronal oscillations to the repetitive speech frequency. ITPC is a measure of consistency of phase values at each time-frequency point over trials (Cohen, 2014). ITPC ranges between 0, indicating randomly distributed phase values, and 1, indicating completely identical phase values. First, we performed time-frequency decomposition with a Hann taper to obtain the Fourier spectrum (amplitude and phase) from -400 ms to 1000 ms in steps of 10 ms, in each electrode. The Fourier spectrum was computed between 0.2 and 30 Hz, with a 0.4 Hz resolution. Epochs were 5 seconds long, from -2000 ms to 3000 ms, to include long buffer zones needed for low-frequency extraction (Cohen, 2014) , with 0 at the repetitive speech vocalization onset. Because ITPC is a sensitive measure to trial count (Cohen, 2014), it was computed in the same number of trials for all conditions and subjects (11 trials, which was the minimum trial count across conditions).

For each time-frequency point, ITPC was calculated as follows: the length of each complex vector resulting from the Fourier transform was normalized to 1, the complex average vector was computed, and its absolute value was obtained (Delorme & Makeig, 2004). For each frequency of interest (i.e., 0.2 Hz and 1 Hz,), ITPC was averaged across timepoints – between -300 and 0 ms (before voice onset) and between 0 and 300 ms (after voice onset) – to obtain a mean ITPC. These time windows were chosen in an exploratory approach since, to our knowledge, no studies have yet measured ITPC during a repetitive speech task. Also, inspection of ITPC time-frequency plots (Figure 5) indicated that it might be relevant to explore before and after voice onset differences among repetitive speech conditions. To test the existence of entrainment to repetitive speech, we compared mean ITPC at 0.2 Hz and at 1 Hz in W0.2 and W1 conditions.

Figure 5

ITPC time-frequency plots in the Cz channel



Note. The dashed lines indicate the time windows where ITPC was computed (-300-0 ms and 0-300 ms).

2.4.3.4. Heart rate and heart rate variability. Effects of repetitive speech on autonomic cardiac modulation were measured through heart rate and HRV frequency-domain indices. ECG epochs had 180 sec (ultra-short-term recordings), a duration that is able to address the main HRV spectral components (Shaffer et al., 2016). HRVanalysis (Pichot et al., 2016) was used to compute heart rate (measured in beats per minute, or bpm) and power spectrum density in the following HRV bandwidths: 0-0.04 Hz for very low-frequency (VLF), 0.04-0.15 Hz for low-frequency (LF), and 0.15-0.40 Hz for high-frequency (HF). High-frequency power is tipically represented in normalized units (HFnu), representing the relative value of this component in proportion to total power (Malik et al., 1996). Thus, HFnu is computed as $HF/(Ptot\text{-}VLF) * 100$, where Ptot is the total power between 0 and 0.40 Hz.

2.5. Behavioural data

Behavioural measures obtained in the auditory oddball task were used to assess the effects of repetitive speech on attention. Following the procedure adopted by Lutz et al. (2009), we measured the average mean reaction time, standard deviation of reaction time, and sensitivity index (d') in response to target tones. Standard deviation of reaction time is a measure of intra-individual variability of behavioural performance. The sensitivity index measures the extent to which participants detect target stimuli from non-target ones, and was computed as $d' = z(H) – z(F)$, where H is the hit rate and F is the false alarm rate (MacMillan & Creelman, 2004). Perfect hit rates (1.0) were corrected to $1\text{-}1/(2n)$ and perfect false alarm rates (0) were corrected to $1/(2n)$, where n corresponds to the maximum possible number of hits and false alarms, respectively (ibd.).

To allow the extraction of vocalization onsets, participants' voice during the repetitive speech tasks was recorded. Audacity® audio editor (Audacity Team, 2019) was used to manually mark the onset of acoustic energy of each word/mantra repetition. Vocalization onset timings were computed as voice triggers, and inserted as events in the EEG MATLAB file.

2.6. Statistical analysis

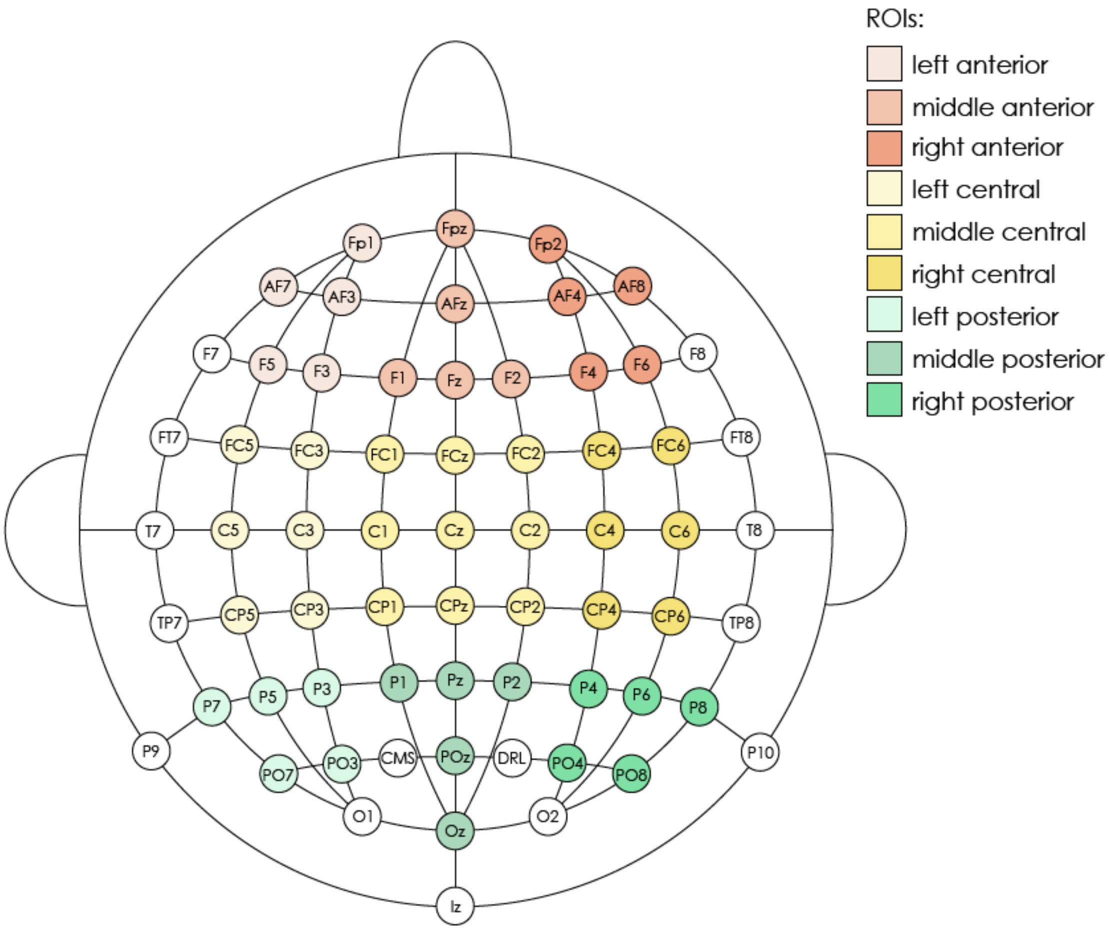
EEG individual channels were organized into nine ROIs according to caudality and laterality (Silva & Castro, 2019; Figure 6): left anterior (FP1, AF3, AF7, F3, F5), middle anterior (Fpz, AFz, F1, Fz, F2), right anterior (Fp2, AF4, AF8, F4, F6), left central (FC3, FC5, C3, C5, CP3, CP5), middle central (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2), right central (FC4, FC6, C4, C6, CP4, CP6), left posterior (P3, P5, P7, PO3, PO7), middle posterior (P1, Pz, P2, POz, Oz) and right posterior (P4, P6, P8, PO4, PO8).

Statistical analysis was conducted with the software JASP (JASP Team, 2020). We tested the effects of mantra and word repetitive speech on attention and autonomic control by comparing M0.2 and W0.2 conditions. Behavioural and autonomic effects were tested using repeated measures ANOVAs with two within-subject factors, utterance (mantra and word) and time (pre and post). Neurophysiological effects were tested with ANOVAs with utterance, time, caudality electrode location (anterior, central, and posterior) and laterality electrode location (left, middle, and right) as within-subject factors (2 x 2 x 3 x 3).

To test entrainment of neural oscillations to the repetition frequency, ITPC at 0.2 Hz and at 1 Hz was compared in conditions W0.2 and W1. ANOVAs were structured as repetition frequency (W0.2 and W1) x entrainment frequency (0.2 Hz and 1 Hz) x caudality (anterior, central, and posterior) x laterality (left, middle, and right). All tests were run with a critical significance level of .05. Greenhouse-Geisser corrections were used for violations of sphericity assumptions and post-hoc tests used Tukey's correction.

Figure 6

Map of EEG channels and ROIs



3. Results

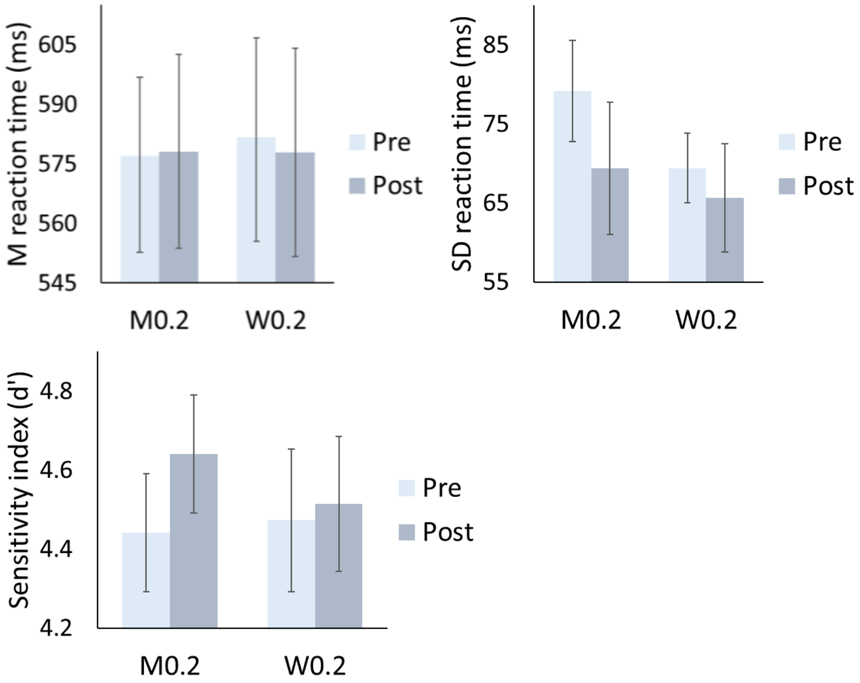
3.1. Effects of repetitive speech on attention

3.1.1. Behavioural results

Figure 7 and Table 1 (Appendix B) present average behavioural results during the oddball task. Mean reaction time increased after M0.2 but decreased after W0.2. However, a repeated measures ANOVA indicated no main effect of utterance ($F(1,11) = 0.06$, $p = .82$) or time ($F(1,11) = 0.03$, $p = .87$), nor interaction between utterance and time ($F(1,11) = 0.09$, $p = .78$). Standard deviation of reaction time was reduced after M0.2 and W0.2, but there was no main effect of utterance ($F(1,11) = 2.04$, $p = .18$) or time ($F(1,11) = 1.59$, $p = .23$), nor interaction between utterance and time ($F(1,11) = 0.71$, $p = .42$). *d'* values increased after both conditions, but again there was no main effect of utterance ($F(1,11) = 0.35$, $p = .57$) or time ($F(1,11) = 2.06$, $p = .18$), nor interaction between utterance and time ($F(1,11) = 0.67$, $p = .43$).

Figure 7

Average behavioural results pre- and post-repetitive speech



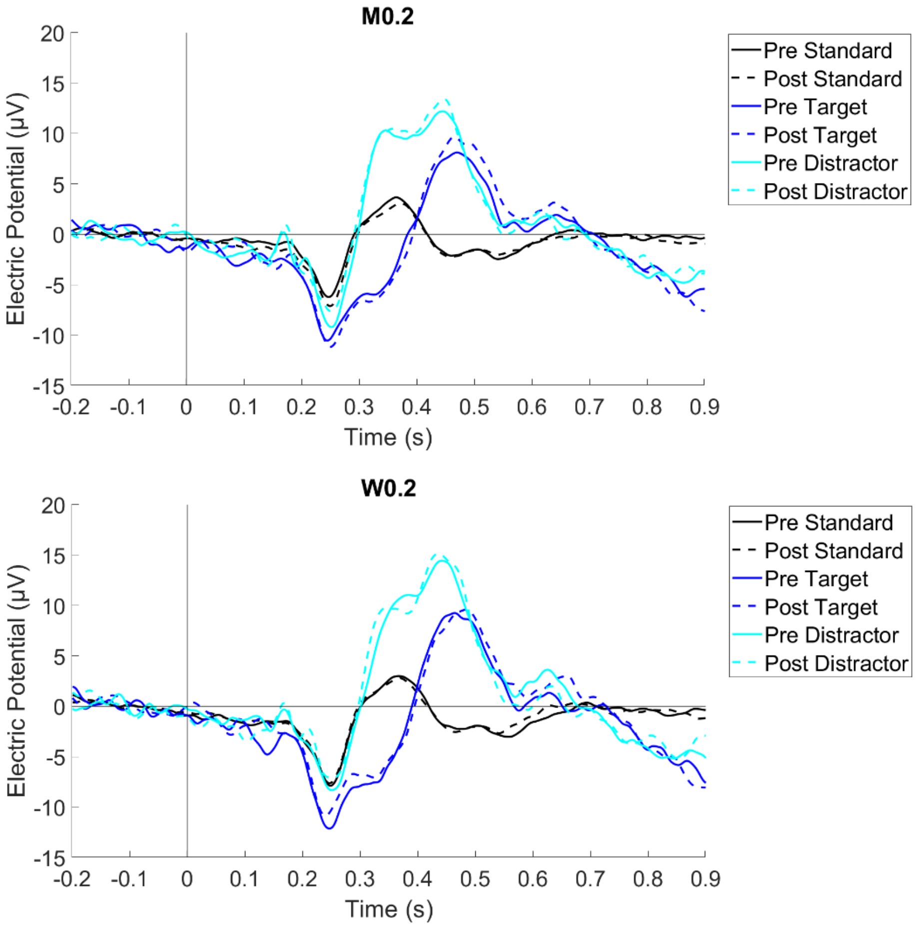
Note. Bars indicate average mean reaction time, average standard deviation of reaction time and median *d'* values for each condition; error bars indicate the standard error of the mean (SE).

3.1.2. Electrophysiological results

3.1.2.1. P3a and P3b mean amplitude. ERPs in response to the oddball task are presented in Figure 8. Mean amplitudes for the P3a and P3b components are described in Tables 2 and 3 (Appendix B). Figure 9 illustrates pre-post changes in P3a and P3b values averaged across all ROIs.

Figure 8

ERPs pre- and post-repetitive speech in the Cz channel

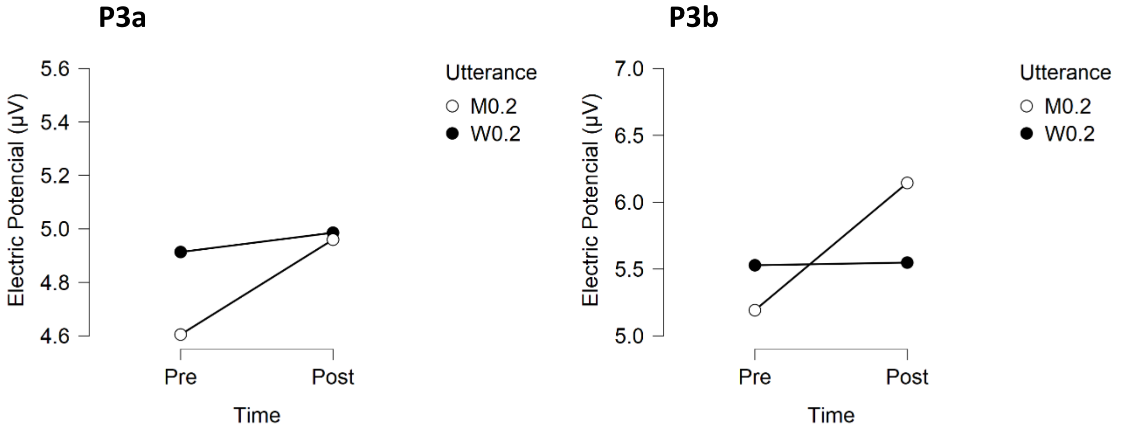


After repetitive speech, the mean amplitude of the P3a component (distractor stimuli between 300-550 ms) increased in most ROIs; exceptions were right anterior and right central in M0.2 and middle and right anterior and right central in W0.2. Repeated-measures ANOVA found no main effect of utterance ($F(1,11) = 0.22$, $p = .65$) or time ($F(1,11) = 0.33$, $p = .58$), nor interaction between utterance and time ($F(1,11) = 0.06$, $p = .82$). No caudality or laterality interactions with utterance or time were found.

Mean amplitude of the P3b component (target stimuli between 400-550 ms) increased after repetitive speech in most ROIs; exceptions were middle and right central and posterior ROIs in W0.2. Repeated-measures ANOVA found no main effect of utterance (*F*(1,11) = 0.03, *p* = .87) or time (*F*(1,11) = 0.51, *p* = .49), nor interaction between utterance and time (*F*(1,11) = 0.26, *p* = .62). An interaction between utterance, time, caudality, and laterality was found (*F*(4,44) = 2.91, *p* = .03), but post-hoc analyses did not indicate any relevant differences. No other caudality or laterality interactions with utterance or time were found.

Figure 9

ERP values averaged across all ROIs pre- and post-repetitive speech



P3a

P3b

3.1.2.2. Theta ERS. Theta ERS in response to the oddball task is presented in Figure 10. Average theta ERS (between 100 and 650 ms) values for each oddball task stimulus are described in Tables 4, 5, and 6 (Appendix B). Figure 11 illustrates pre-post changes in theta ERS averaged across all ROIs.

After M0.2, theta ERS for target stimuli increased in anterior ROIs and left and middle central; after W0.2, it increased in middle anterior and posterior ROIs (see Table 4, Appendix B). Repeated measures ANOVA found a main effect of utterance (*F*(1,11) = 4.68, *p* = .05, ω^2[2] = .01), but no main effect of time (*F*(1,11) = 0.02, *p* = .89), indicating that both pre- and post-values of W0.2 were higher than values of M0.2. There was no interaction between utterance and time (*F*(1,11) = 0.08, *p* = .79), nor interactions between caudality and laterality with utterance and time.

Theta ERS for distractor stimuli decreased in all ROIs after M0.2, but only in right ROIs and middle posterior after W0.2 (see Table 5, Appendix B). No main effect of utterance

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[2] Omega squared is an unbiased effect size measure for small samples and is interpreted as: < 0.01 trivial, 0.01 small, 0.06 medium, and 0.14 large (Goss-Sampson, 2019).

($F(1,11) = 0.04$, $p = .86$) or time ($F(1,11) = 1.40$, $p = .26$), nor interaction between utterance and time ($F(1,11) = 1.43$, $p = .26$) was found. A significant interaction between utterance, time, and laterality was found ($F(2,22) = 4.14$, $p = .03$, $\omega^2 = .004$), but post-hoc tests did not indicate any relevant differences. No other significant interactions were found.

After both conditions of repetitive speech, theta ERS for standard stimuli decreased in all ROIs (see Table 6, Appendix B). A main effect of time was found ($F(1,11) = 16.91$, $p = .002$, $\omega^2 = .09$), indicating a significant reduction of theta ERS for standard stimuli after both M0.2 and W0.2. There was no main effect of utterance ($F(1,11) = 4.28$, $p = .06$) nor a significant interaction between utterance and time ($F(1,11) = 0.18$, $p = .68$). No interaction between caudality and laterality with utterance and time was found.

Figure 10

Theta ERS pre- and post-repetitive speech in the Cz channel

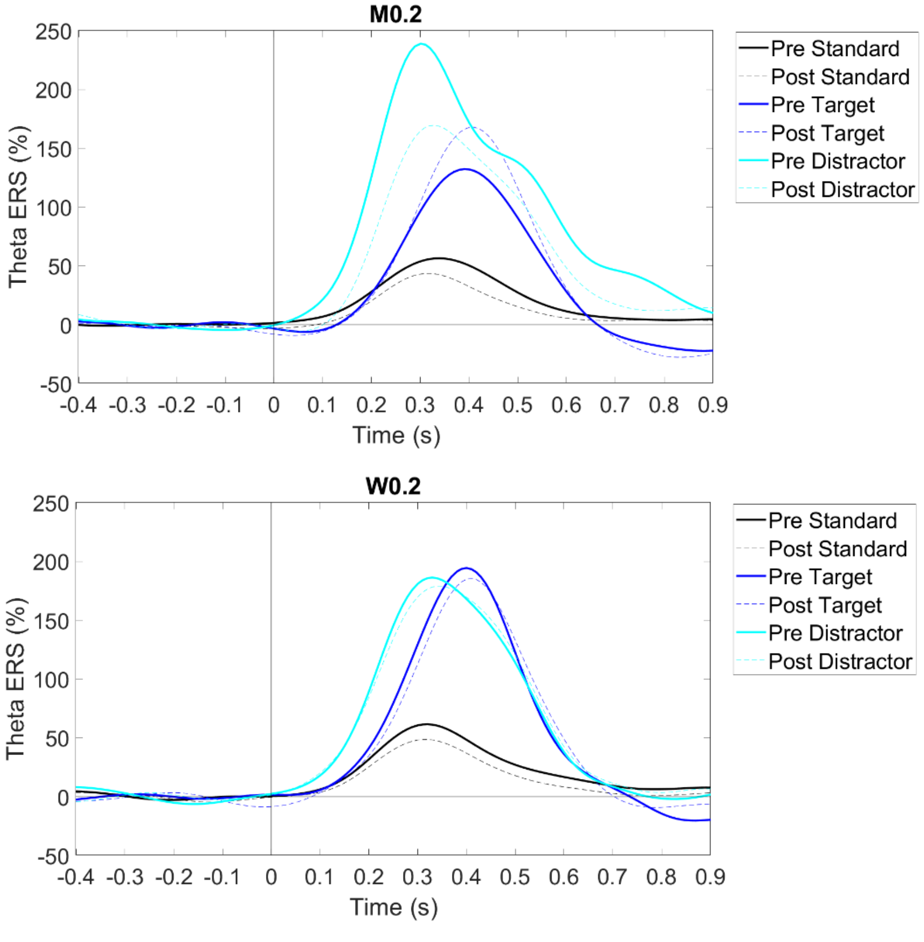
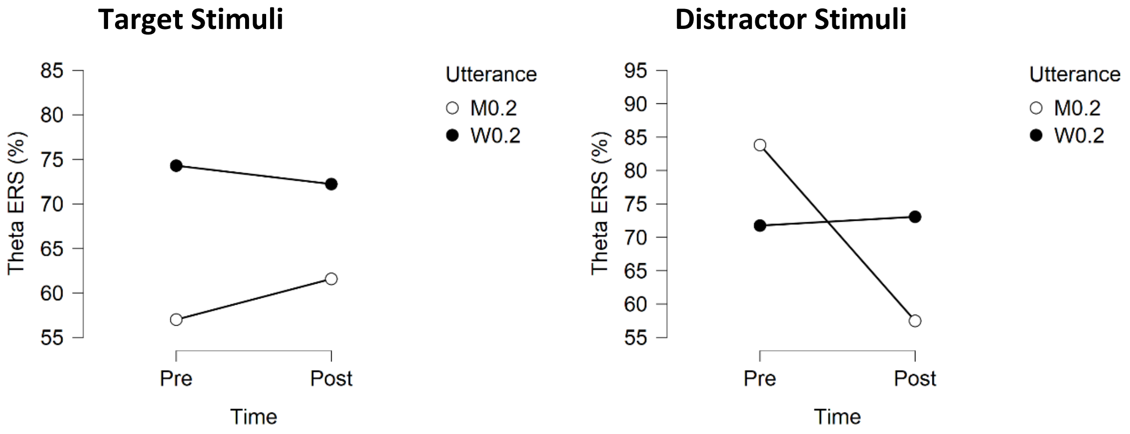
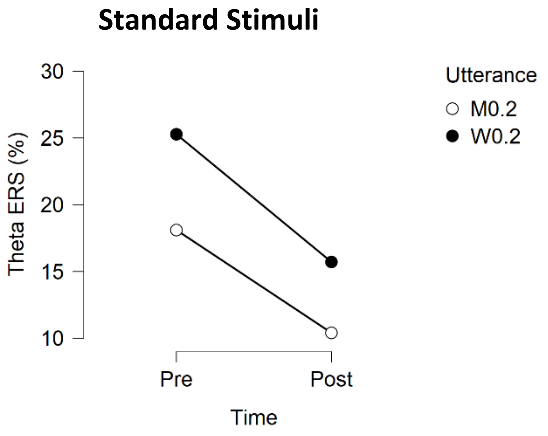


Figure 11

Theta ERS values averaged across all ROIs pre- and post-repetitive speech





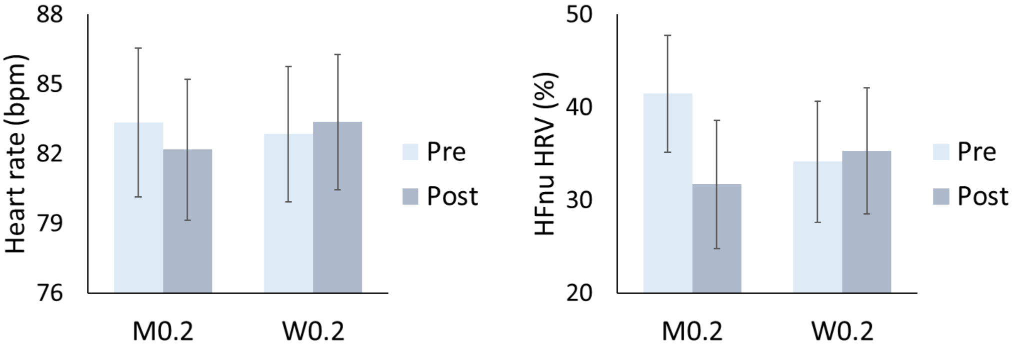
3.2. Effects of repetitive speech on autonomic control

Table 7 (Appendix B) and Figure 12 present average autonomic control results. Heart rate decreased after M0.2, but increased after W0.2. Repeated measures ANOVA indicates no main effect of utterance ($F(1,11) = 0.18$, $p = .68$), time ($F(1,11) = 0.26$, $p = .62$), nor an interaction between utterance and time ($F(1,11) = 1.28$, $p = .28$).

HFnu HRV increased after W0.2, but decreased after M0.2. There was no main effect of utterance ($F(1,11) = 0.29$, $p = .60$), time ($F(1,11) = 2.24$, $p = .16$), but an interaction between utterance and time was found ($F(1,11) = 5.20$, $p = .04$). However, post-hoc tests did not find any significant difference.

Figure 12

Average autonomic control results pre- and post-repetitive speech



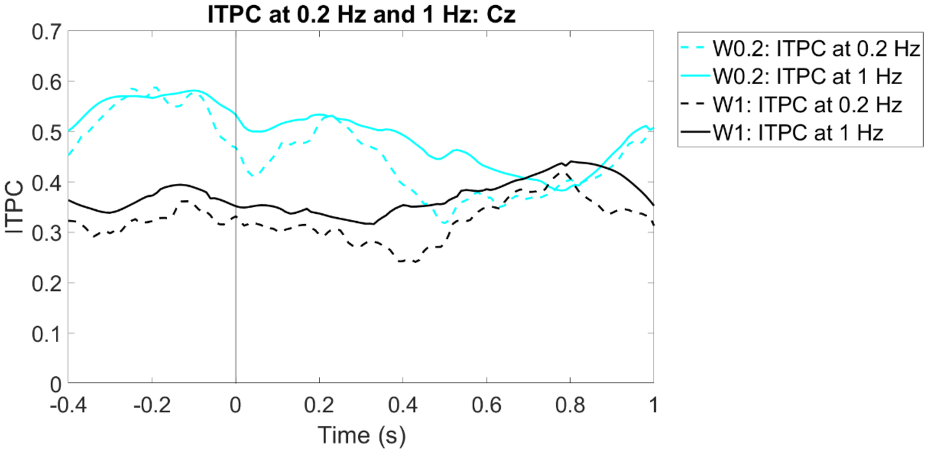
Note. Bars indicate average heart rate and high-frequency HRV in normalized units for each condition; error bars indicate the standard error of the mean (SE).

3.3. Entrainment to repetitive speech

Figure 13 represents ITPC values at 0.2 Hz and 1 Hz in the Cz channel for conditions W0.2 and W1. Tables 8 and 9 (Appendix B) present repetitive speech frequency ITPC at 0.2 Hz and at 1 Hz for each condition, before (from -300 to 0 ms) and after (from 0 to 300 ms) voice onset, respectively. Figure 14 illustrates pre-post changes in ITPC values averaged across all ROIs.

Figure 13

ITPC at 0.2 Hz and at 1 Hz in the Cz channel



Repeated measures ANOVAs found a main effect of repetition frequency before voice onset ($F(1,11) = 6.75$, $p = .03$, $\omega^2 = .21$) and after voice onset ($F(1,11) = 12.25$, $p = .01$, $\omega^2 = .23$), indicating that condition W0.2 presented higher ITPC values than W1. There was also a main effect of entrainment frequency before ($F(1,11) = 57.42$, $p < .001$, $\omega^2 = .03$) and after voice onset ($F(1,11) = 25.92$, $p < .001$, $\omega^2 = .03$), with ITPC at 1 Hz being higher than ITPC at 0.2 Hz.

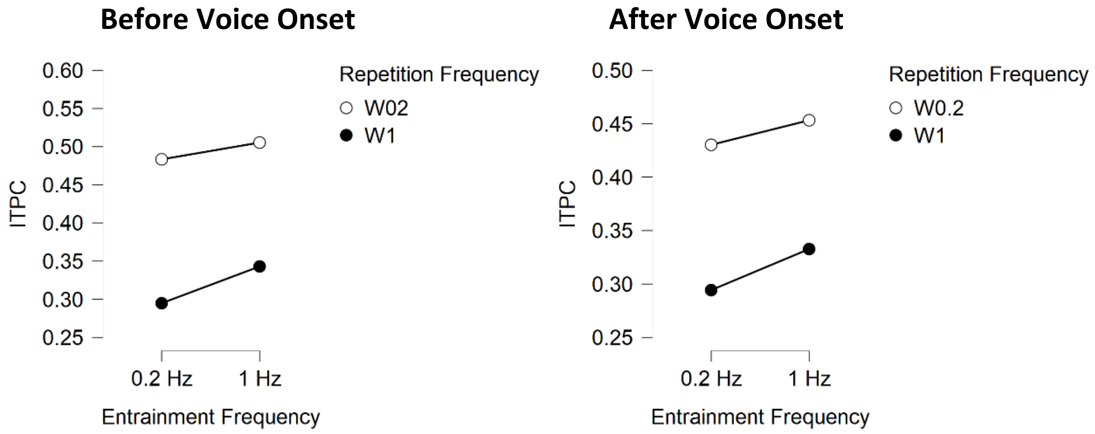
Before voice onset, there was an interaction between entrainment frequency and repetition frequency ($F(1,22) = 4.80$, $p = .05$, $\omega^2 = .003$). Post-hoc tests indicate that ITPC at 0.2 Hz was significantly lower than ITPC at 1 Hz in W0.2 ($t = -2.91$, $p_{\text{tukey}} = .039$) and in W1 ($t = -6.37$, $p_{\text{tukey}} < .001$). There was also an interaction between repetition frequency and laterality ($F(2,22) = 7.64$, $p = .003$, $\omega^2 = .03$); post-hoc analysis indicates significantly lower ITPC in left ROIs than in right ROIs in W0.2 ($t = -4.12$, $p_{\text{tukey}} = .002$). No other significant interactions were found in this time window.

After voice onset, there was no interaction between entrainment frequency and repetition frequency ($F(1,11) = 2.43$, $p = .15$), but an interaction between repetition frequency, entrainment frequency, and caudality was found ($F(2,22) = 5.00$, $p = .02$, $\omega^2 = .002$). Post-hoc tests indicate that, in W1, ITPC at 0.2 Hz was significantly lower than ITPC at 1 Hz in anterior ROIs ($t = -5.00$, $p_{\text{tukey}} < .001$) and in central ROIs ($t = -4.39$, $p_{\text{tukey}} = .004$). No other significant interactions were found in this time window.

As evidence of entrainment to the repetition frequency, we hypothesized that W0.2 would produce stronger ITPC at 0.2 Hz than at 1 Hz, and that W1 would produce stronger ITPC at 1 Hz than at 0.2 Hz. Since ITPC at 1 Hz was stronger than ITPC at 0.2 Hz independently of the repetitive speech condition, no evidence of entrainment to the repetition frequency was found. Therefore, we did not proceed to test the association between entrainment and task-related attentional gains (H_A 2.2).

Figure 14

ITPC at 0.2 Hz and at 1 Hz during repetitive speech averaged across all ROIs



4. Discussion

This study had two main objectives. First, we aimed to understand if repetitive speech with a mantra and repetitive speech with words would elicit the expected behavioural and electrophysiological correlates of mantra meditation in a similar way. Secondly, we aimed to understand if repetitive speech would elicit neural entrainment at the repetition frequency, and if this entrainment would correlate with task-related attentional gains.

4.1. Repetitive speech effects on attention

Regarding the first objective, effects of repetitive speech were observed in neural markers of attention. After both M0.2 and W0.2, participants responded less to standard stimuli, as indicated by reduced theta ERS. Repetitive speech with a mantra and repetitive speech with words were equally able to reduce responsivity to non-targets, which adds evidence to the idea that the repeated utterance of speech is a fundamental component of mantra meditation.

The hypothesized attentional effects (H_A 1.1 and 1.2) were not observed in all markers. From the eight attentional measures, the most sensitive to repetitive speech effects was theta ERS in response to standard tones (neural response to non-target stimuli). Some measures were non-significantly affected by repetitive speech: P3b mean amplitude (neural response to target stimuli) increased in most ROIs and *d'* values (sensitivity index) increased after both conditions; standard deviation of reaction time (variability in response to target stimuli) decreased after both conditions. Other measures – mean reaction time (sensitivity to target stimuli) and theta ERS in response to target tones (neural response to target stimuli) – did not seem to be affected by repetitive speech. Finally, one measure presented a behaviour against expectations: P3a mean amplitude (neural response to distractor stimuli) increased after repetitive speech instead of decreasing.

Theta ERS values in response to distractor tones (neural response to non-target stimuli) and P3b mean amplitude values (neural response to target stimuli) suggest that this marker might be more sensitive to M0.2 than W0.2. While no significant interaction was found, pre-post changes in both conditions show that theta ERS to distractors was relevantly reduced after M0.2, but not after W0.2 (Figure 11), and that P3b increased after M0.2 but not after W0.2 (Figure 9). These differences suggest that the mantra "om" might present specific acoustic characteristics which enhance attention focusing. Interestingly, reading Sanskrit produces neural effects similar to those of mantra meditation (Travis et al., 2001), which indicates that an important component of mantra meditation might rely on its acoustics. Future studies should look into the acoustic and phonological characteristics of mantras and Sanskrit phonemes.

To our knowledge, this is the first study to measure the behavioural and neural markers of an auditory oddball task after repetitive speech or mantra meditation. In line with the expected results for meditation (Cahn & Polich, 2009; Lutz et al., 2009; Telles et al., 2019), we showed that the continuous repetition of a mantra and the continuous repetition of words are equally able to reduce responsivity to non-target stimuli. Decreased processing of standard stimuli was observed in all ROIs and with a medium effect size, suggesting a widespread neural effect of repetitive speech.

4.2. Repetitive speech effects on autonomic control

Also within the first objective of this study, we did not find evidence of mantra and word repetitive speech affecting autonomic control in a similar way. After M0.2, the parasympathetic activity increased and the sympathetic activity decreased, as indexed by heart rate slowing; simultaneously, high-frequency HRV decreased, puzzingly suggesting reduced parasympathetic control. After W0.2, heart rate was higher but high-frequency HRV improved, indicating increased parasympathetic activity.

High-frequency HRV results for the M0.2 condition go against expectations. First, this condition seems to have induced heart rate slowing. Second, meditation in general, and mantra meditation in particular, are tipically associated with increased parasympathetic control (Tang et al., 2009; Travis, 2001). Yet, there is evidence that high-frequency HRV might decrease after other types of FA meditation (Telles et al., 2018), and therefore it is possible that this measure is non-linearly affected by meditation. Furthermore, our results should be interpreted with caution, since high-frequency HRV ranges in the respiratory frequency-band and the respiratory rate was not measured and controled for (Berntson et al., 2007). Since participants were not experienced mantra-meditators, it is possible that repetitive speech might have induced some breathing effort, changing the HRV frequency range.

4.3. Entrainment of brain oscillations during repetitive speech

Regarding the second objective of the study, evidence of entrainment at the repetition frequency during repetitive speech was not found, since ITPC at 1 Hz was stronger than ITPC at 0.2 Hz independently of the repetitive speech condition. Interestingly, ITPC time-frequency plots (Figure 5) suggest that entrainment at delta-band was stronger than entrainment at the other frequency bands. Strong delta entrainment is predicted by studies on continuous speech, which indicate that delta entrainment is an important process for speech encoding (Ding & Simon, 2014). Contrarily to what we hypothesized, entrainment during repetitive speech might not happen strictly due to the rate of utterance repetition, but rather due to the various acoustic characteristics of speech, which range in the delta-band. It is also unknown whether entrainment might be stronger for repetitive speech than for continuous speech; the answer to this question might shed more light into the neural mechanisms of mantra meditation.

A second important result was that W0.2 elicited significantly more entrainment than W1, both at 0.2 Hz and at 1 Hz, with a large effect size (Figure 14). This suggests that cortical entrainment during repetitive speech might require an optimal utterance repetition rate, that possibly should not be too fast. The strong cortical entrainment at 0.2 Hz and 1 Hz in W0.2 might be a reflex of general delta-band entrainment. In fact, ITPC time-frequency plots (Figure 5) suggest a relevant difference between the conditions, with delta-band entrainment at W0.2 being stronger than at W1.

Oscillatory entrainment, particularly at delta band, is associated with selective attention (Schroeder & Lakatos, 2009). We therefore hypothesized (H_A 2.2) that increases in delta phase coherence during repetitive speech would relate with theta power changes due to repetitive speech. However, since no evidence of entrainment at the repetition frequency was found, we did not test the existence of such correlation. An important point is that theta power changes were not measured during repetitive speech but afterwards. If theta power was measured during repetitive speech, it could be tested whether there were theta power gains during repetitive speech, and if these related with delta phase coherence. In fact, entrainment subserves attention due to the mechanism of phase-amplitude coupling, by which the amplitude of high-frequency oscillations relates with the phase of low-frequency ones (Calderone et al., 2014). Future studies should test the existence of delta-theta phase-amplitude coupling during repetitive speech.

4.4. Limitations and conclusions

The results of this study should be interpreted with caution due to some limitations. First, our sample size was reduced and consisted only of young women. While a number of 10-20 participants is typical in electrophysiological studies (Luck, 2014), it is possible that some pre-post repetitive speech differences did not reach statistical significance due to the limited sample size. Second, although participants were asked to focus attention on the repeated utterance, it would still be possible to produce repetitive speech with reduced attention on it. One way to control the focus of attention during the task might be to ask participants to report on their attention at the end of the experiment. Third, it is possible that repetitive speech might have disturbed the normal respiratory rate. Because respiratory rate was not measured, the accuracy of high-frequency HRV measurement is unknown.

Although studies on the effects of meditation in human health and well-being are increasing in the last years, little is known about the neurophysiological processes involved and this research area has been considered to be in its infancy (Davidson & Kaszniak, 2015; Lutz et al., 2008). Particularly concerning mantra meditation, few studies have reported neurophysiological findings, and more importantly, few have tried to isolate its different components in order to understand its neurocognitive mechanisms. This study was based on the hypothesis that repetitive speech is a fundamental component of mantra meditation (Berkovich-Ohana et al., 2015). Agreeing with our hypothesis, we found that mantra repetitive speech and word repetitive speech were equally able to decrease responsivity to non-target stimuli. However, we did not find evidence of entrainment of neural oscillations to the repetition frequency. Our results agree with Berkovich-Ohana et al.'s research on the effects of repetitive speech on neural markers, as we evidenced that the continuous and rhythmic repetition of words is able to produce mantra meditation-like effects on attention.

Future studies might broaden the available knowledge on mantra meditation by comparing entrainment during continuous and repetitive speech, by testing if entrainment modulates attention during repetitive speech, by analysing the neurocognitive effects of repeating different mantra phonemes, and by measuring the effects of different repetition rates.

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Appendices

Appendix A
Informed Consent for the Participants

Informação para o Participante

Este estudo laboratorial tem como objetivo investigar de que modo a meditação altera a nossa capacidade de atenção. Para tal, usamos uma tarefa que consiste em repetir em voz alta uma palavra, ou conjunto de palavras, durante alguns minutos, seguida por outra tarefa de atenção auditiva.

Vimos solicitar a sua participação neste estudo, que envolverá a gravação da atividade cerebral e cardíaca através de um sistema de eletroencefalografia (EEG) e eletrocardiografia (ECG), no Laboratório de Fala da FPCEUP. A duração da experiência é de cerca de 60 minutos. Para além disto, ser-lhe-á colocada uma touca com eléctrodos, um elétrodo no tornozelo e outro no pulso, processo este que demora cerca de 30 minutos.

Os dados pessoais que nos facultar serão confidenciais e os resultados obtidos neste estudo serão utilizados apenas para alcançar os objetivos da investigação. A sua participação é voluntária e pode ser interrompida a qualquer momento, caso assim o entenda.

Estamos disponíveis para esclarecer qualquer dúvida que possa surgir.

Declaração de Consentimento Informado

Eu, ____, abaixo-assinado, compreendi a explicação escrita e oral que me foi fornecida acerca da investigação que se tenciona realizar, e para qual é pedida a minha participação. Li a informação que me foi previamente dada sobre recolha de dados de EEG e ECG. Pude fazer as perguntas que julguei necessárias, e para todas obtive resposta satisfatória.

Foi-me dada informação sobre os objetivos, os métodos, os benefícios previstos, os riscos potenciais e eventuais momentos de desconforto inerentes à minha participação. Além disso, foi-me dito que tenho o direito de aceitar ou recusar livremente e a qualquer momento a minha participação no estudo. Sei que, se recusar, não haverá qualquer prejuízo na assistência que me é prestada. Após a experiência, poderei contactar a investigadora responsável para obter mais informação acerca do estudo ou de conhecer os seus resultados, através do email labfala@fpce.up.pt.

Foi-me dado todo o tempo de que necessitei para refletir sobre esta proposta de participação.

Nestas circunstâncias, decido livremente aceitar participar neste projeto de investigação, tal como me foi apresentado pela investigadora.

_____ de _____________ de 2020

____

Assinatura d@ Participante

Appendix B

Tables of Results

Table 1

Average behavioural results pre- and post-repetitive speech (M ± SD)

	M0.2		**W0.2**	
	Pre	Post	Pre	Post
mean reaction time (ms)	577.00 (68.42)	578.13 (84.30)	581.65 (86.71)	577.86 (90.77)
st. dev. reaction time (ms)	79.20 (22.16)	69.37 (28.94)	69.41 (15.23)	65.64 (23.73)
d'	4.44 (0.50)	4.64 (0.51)	4.47 (0.63)	4.51 (0.57)

Table 2

Average P3a mean amplitude (µV) results pre- and post-repetitive speech (M ± SD)

ROI	**M0.2**		**W0.2**	
	Pre	Post	Pre	Post
left anterior	4.20 (4.98)	4.98 (5.02)	4.18 (4.33)	4.24 (4.20)
middle anterior	5.92 (5.77)	6.38 (5.45)	6.09 (5.37)	5.41 (4.38)
right anterior	4.28 (4.64)	4.17 (4.92)	3.88 (5.19)	3.01 (4.41)
left central	5.02 (3.88)	5.44 (3.09)	5.25 (2.98)	5.97 (3.55)
middle central	7.32 (5.30)	7.63 (4.57)	8.02 (4.61)	8.13 (4.43)
right central	4.53 (4.07)	4.51 (4.07)	4.72 (4.12)	4.72 (3.62)
left posterior	3.09 (3.04)	3.61 (2.32)	3.80 (1.69)	4.21 (2.61)
middle posterior	4.01 (3.10)	4.55 (2.66)	4.88 (2.16)	5.26 (2.49)
right posterior	3.08 (3.66)	3.38 (2.65)	3.41 (2.37)	3.93 (2.92)
average ROIs	4.60 (4.39)	4.96 (4.08)	4.91 (3.96)	4.99 (3.82)

Table 3

Average P3b mean amplitude (µV) pre- and post-repetitive speech (M ± SD)

ROI	**M0.2**		**W0.2**	
	Pre	Post	Pre	Post
left anterior	5.02 (4.82)	5.34 (4.79)	3.95 (2.19)	5.81 (5.22)
middle anterior	5.12 (5.14)	6.41 (4.94)	5.16 (2.31)	5.93 (5.98)
right anterior	3.08 (4.21)	4.81 (4.49)	3.19 (1.74)	3.66 (6.19)
left central	4.88 (3.45)	5.31 (3.77)	4.97 (2.02)	5.33 (4.95)
middle central	5.80 (4.70)	6.92 (4.46)	6.61 (2.53)	6.47 (6.07)
right central	3.71 (2.89)	5.40 (3.67)	4.74 (1.55)	4.29 (4.45)
left posterior	6.19 (3.52)	6.59 (3.02)	6.73 (2.46)	5.71 (4.33)
middle posterior	7.16 (3.15)	7.85 (3.44)	7.86 (2.63)	7.02 (4.53)
right posterior	5.77 (2.38)	6.68 (3.52)	6.56 (2.58)	5.71 (3.63)
average ROIs	5.19 (3.94)	6.14 (4.02)	5.53 (2.59)	5.55 (5.01)

Table 4

Average theta ERS (%) for target stimuli pre- and post-repetitive speech (M ± SD)

ROI	M0.2		W0.2	
	Pre	Post	Pre	Post
left anterior	46.33 (45.21)	66.87 (52.66)	69.45 (38.76)	64.11 (42.53)
middle anterior	65.57 (61.13)	78.79 (61.11)	85.97 (53.81)	86.66 (64.27)
right anterior	51.93 (47.25)	59.04 (45.96)	73.25 (63.65)	62.23 (48.07)
left central	56.35 (53.37)	75.04 (83.69)	88.63 (72.83)	75.94 (66.26)
middle central	72.68 (67.98)	80.95 (87.86)	96.78 (78.65)	95.18 (87.55)
right central	73.05 (66.55)	62.69 (64.43)	80.72 (56.55)	77.88 (73.06)
left posterior	44.41 (47.60)	42.73 (69.77)	57.65 (69.49)	95.18 (87.55)
middle posterior	55.55 (47.58)	49.85 (63.91)	63.87 (63.58)	67.98 (62.48)
right posterior	47.18 (49.53)	38.21 (55.53)	52.26 (51.49)	59.33 (61.82)
average ROIs	57.00 (53.61)	61.57 (65.42)	74.29 (61.35)	72.22 (63.27)

Table 5

Average theta ERS (%) for distractor stimuli pre- and post-repetitive speech (M ± SD)

ROI	**M0.2**		**W0.2**	
	Pre	Post	Pre	Post
left anterior	94.64 (60.36)	53.68 (57.22)	78.26 (68.03)	89.09 (74.56)
middle anterior	111.85 (63.59)	91.37 (90.96)	99.69 (84.94)	105.87 (72.69)
right anterior	76.86 (50.24)	60.48 (45.22)	80.10 (67.50)	68.34 (47.23)
left central	90.84 (74.13)	57.34 (70.33)	64.64 (69.11)	80.25 (91.89)
middle central	129.55 (78.27)	89.71 (88.98)	102.00 (93.52)	105.16 (83.18)
right central	96.63 (61.70)	72.48 (58.35)	97.66 (85.28)	77.81 (61.96)
left posterior	45.32 (37.47)	27.43 (58.02)	27.37 (63.55)	42.53 (61.44)
middle posterior	56.15 (45.45)	33.73 (53.07)	47.03 (74.20)	45.89 (60.05)
right posterior	52.53 (37.77)	31.10 (41.22	49.02 (64.53)	42.66 (58.84)
average ROIs	83.82 (62.18)	57.48 (66.30)	71.75 (76.58)	73.07 (70.71)

Table 6

Average theta ERS (%) for standard stimuli pre- and post-repetitive speech (M ± SD)

ROI	**M0.2**		**W0.2**	
	Pre	Post	Pre	Post
left anterior	18.25 (17.99)	9.95 (13.44)	26.61 (19.91)	15.47 (19.43)
middle anterior	24.65 (17.92)	18.45 (16.31)	33.62 (21.38)	21.43 (20.63)
right anterior	17.15 (14.14)	11.25 (9.45)	29.14 (20.78)	14.48 (15.77)
left central	20.70 (16.41)	13.14 (18.65)	28.07 (24.29)	18.27 (19.56)
middle central	29.36 (17.46)	19.80 (19.00)	33.99 (23.21)	24.47 (20.32)
right central	20.71 (12.75)	13.83 (10.38)	25.79 (15.38)	17.02 (13.44)
left posterior	11.64 (12.18)	-0.15 (13.46)	12.36 (17.09)	8.90 (11.72)
middle posterior	12.71 (13.06)	4.56 (15.32)	15.38 (18.44)	12.76 (11.22)
right posterior	7.72 (9.77)	2.80 (9.48)	22.49 (41.02)	8.57 (10.23)
average ROIs	18.10 (15.68)	10.40 (15.27)	25.27 (23.66)	15.71 (16.48)

Table 7

Average autonomic control results pre- and post-repetitive speech (M ± SD)

	M0.2		**W0.2**	
	Pre	Post	Pre	Post
heart rate (bpm)	83.35 (11.08)	82.17 (10.51)	82.85 (10.08)	83.36 (10.05)
HFnu HRV (%)	41.45 (21.74)	31.68 (23.81)	34.13 (22.51)	35.30 (23.43)

Table 8

Before voice onset (-300-0 ms) ITPC at 0.2 Hz and at 1 Hz during repetitive speech (M ± SD)

ROI	**W0.2**		**W1**	
	0.2 Hz	1 Hz	0.2 Hz	1 Hz
left anterior	.40 (.28)	.43 (.26)	.35 (.18)	.39 (.19)
middle anterior	.48 (.28)	.48 (.27)	.32 (.15)	.37 (.16)
right anterior	.50 (.24)	.51 (.23)	.34 (.14)	.40 (.15)
left central	.48 (.28)	.49 (.28)	.30 (.11)	.35 (.13)
middle central	.53 (.25)	.55 (.24)	.30 (.09)	.35 (.10)
right central	.56 (.22)	.58 (.22)	.27 (.06)	.31 (.07)
left posterior	.43 (.23)	.45 (.22)	.27 (.08)	.31 (.09)
middle posterior	.50 (.20)	.52 (.19)	.27 (.08)	.32 (.09)
right posterior	.52 (.21)	.54 (.21)	.25 (.08)	.29 (.11)
average ROIs	.48 (.24)	.51 (.23)	.29 (.11)	.34 (.13)

Table 9

After voice onset (0-300 ms) ITPC at 0.2 Hz and at 1 Hz during repetitive speech (M ± SD)

ROI	**W0.2**		**W1**	
	0.2 Hz	1 Hz	0.2 Hz	1 Hz
left anterior	.38 (.20)	.40 (.20)	.28 (.12)	.33 (.13)
middle anterior	.41 (.22)	.42 (.21)	.30 (.12)	.35 (.11)
right anterior	.46 (.16)	.47 (.15)	.29 (.12)	.34 (.13)
left central	.41 (.20)	.44 (.20)	.30 (.12)	.35 (.12)
middle central	.44 (.21)	.47 (.21)	.31 (.10)	.35 (.12)
right central	.49 (.18)	.52 (.17)	.29 (.10)	.33 (.10)
left posterior	.39 (.15)	.43 (.15)	.29 (.09)	.32 (.10)
middle posterior	.43 (.17)	.46 (.17)	.29 (.09)	.31 (.09)
right posterior	.46 (.19)	.48 (.18)	.30 (.08)	.32 (.09)
average ROIs	.43 (.18)	.45 (.18)	.29 (.10)	.33 (.11)