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Dynamic range adaption of the N1m component elicited by intensity-modulated tones and its relation to musicality

Inauguraldissertation
zur Erlangung des Doctor scientiarum humanarum (Dr. sc. hum.)
an der
Medizinischen Fakultät Heidelberg
der
Ruprecht-Karls-Universität

vorgelegt von
Kristin Held
geboren in
Ludwigsfelde

2023

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Learning is a treasure
that will follow its owner everywhere.

-Unkown-

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Abbreviations

AC	Auditory cortex
AEF/AEP	Auditory evoked field/potential
AMMA	Advanced Measure of Music Audiation
BEM	Boundary element method
BESA®	Brain Electric Source Analysis
BOLD	Blood oxygen level dependent
dB	Decibel
DFG	German Research Foundation
DRA	Dynamic Range Adaption
ECD	Equivalent current dipoles
fMRI	Functional magnetic resonance imaging
GTT	Transverse temporal gyrus
EEG	Electroencepahlography
HG	Heschl's gyrus
HPI	Head Position Indicator Coils
Hz	Hertz
ICA	Independent component analysis
ISI	Interstimulus Interval
ITI	Inter Train Interval
MATLAB	MATrix LABoratory
MEG	Magnetoencephalography
PAC	Primary auditory cortex
POR	Pitch-Onset-Response
PT	Planum temporale
SAS	Statistical Analysis System
SOA	Stimulus Onset Asynchrony
SPL	Sound pressure level
STG	Superior temporal gyrus
SQUID	Superconducting quantum interference devices
RV	Residual variance

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Preface

The present thesis addresses the question of dynamic range adaption of the N1m component elicited by intensity-modulated tones. Building upon the existing research base, the present work aims to gain a deeper understanding of the auditory N1m component by studying the effects in regard to dynamic range adaption and its relation to musicality. The first steps were taken by looking at the specific neuromagnetic component, which is reflected in amplitude variation to the different characteristics of the stimulus applied (variation in intensity and spacing of stimuli). Then based on these steps, the data was studied for the effects of musicality. Most of these aspects have been looked at in auditory research before but have never been set in relation to each other. The present thesis aims to close this gap by replicating known effects and looking at each of the effects under the scope of the used study design as well as the relation of the effects to one another.

The processing of tones starts when a sound reaches the ear and continues down the auditory pathway. The first part of the introduction (chapter 1) to this thesis gives a quick review of the neuroanatomy of the auditory pathway (section 1.1). Most relevant to the effects studied here is the present knowledge of the cortical processing of the auditory potentials. In particular, the effects of the N1m were studied, and thus, the second part of the literature basis focuses on the N1/N1m research done to this date. Since this is also a broad field, this section focuses on the relevant studies on cortical origins and amplitude variation of sound intensity and interstimulus intervals (section 1.2). This part is followed by a brief review of the habituation vs. recovery approach of the N1/N1m, which gives a base for the investigated dynamic range adaption hypothesis (section 1.3). For the aspects of musicality, the next sections give an insight into musicality in early cortical processing and the AMMA test, which was used in this thesis as a measurement of musicality (section 1.4 & section 1.5). The introduction concludes with literature on source analysis methods used to evaluate the magnetoencephalographic data in the present study (section 1.7). The next part presents the hypotheses, which were investigated for this thesis based on the research presented in the prior sections, followed by chapter 3 with the presentation of the materials and methods used. The sections within chapter 2 list the hypotheses, which are ordered according to the process of evaluation, where each hypothesis includes the two central issues addressed (amplitude variation and interstimulus interval). Following this chapter, the next part gives a greater insight into the participants, stimulation, data acquisition, and the analysis procedures of the data sets used in this study. Chapter 4 then shows the results of the data analysis, starting with the AMMA testing outcome, followed by the source analysis and statistical testing results section. The presentation of the results follows the same logic as the presented hypothesis in chapter 2. Each section looks at the hypotheses of the examined variable, within which the two central questions are also represented by a hypothesis within the area of research (sections 4.2, 4.3, 4.4, 4.5). The next part of this thesis is devoted to discussing the findings and fitting these into the greater picture of the prior existing research (chapter 5). The section here addresses the effects of the N1m component concerning the interstimulus effects and the intensity effects (section 5.1) and dynamic range adaption (section 5.2), as well as the interactions between these aspects followed by the presentation of the effects of musicality (section 5.3) and the interaction with dynamic range adaption effects (section 5.4). The last part of this work includes the conclusions drawn from this study as well as an outlook into aspects, which could not be further considered in this thesis but could present a gainful next step for further research (chapter 6).

1. Introduction

1.1. Neuroanatomy of the auditory pathway

Since the primary aim of this thesis focuses on the processing of sound, the following paragraphs will start with a review of the anatomy of the auditory pathway and give a closer look at the auditory processing at cortical levels. Sound processing begins when a sound wave reaches the outer ear and is then transmitted into the middle ear, where it passes through the ascending auditory pathway before reaching the cortical processing levels.

The sound, transmitted through the air, is perceived when the waves reach the earlobes (*Auricula*). The primary function of the earlobe is to enable the directional hearing process (Trepel, 2015). Once the sound wave reaches the outer ear canal (*Meatus acusticus externus*), it is passed on to the middle (inner) ear and directed towards the eardrum (*Membrana tympanica*). The purpose of the middle ear is to efficiently transmit the sound from the air-filled compartment (with low conductive resistance) into the fluid-filled parts (with high conductive resistance) by concentrating the pressure of the wave onto a particular small part of the oval window (Schnupp et al., 2011). Based on this mechanism, even small airwaves can be collected and transferred into the cochlear-filled compartments (Schnupp et al., 2011). Within the middle ear lies the cochlea, with the basilar membrane, which also carries the organ of Corti (Yates, 1995). The organ of Corti has two essential properties of mechanical resistance: the basilar membrane's stiffness and the fluid's inertia. These properties lead to the fact that there are different "best" frequencies along the cochlea, where it vibrates at an optimum. It, therefore, functions like a mechanical frequency analyzer (Schnupp et al., 2011). The fact that different frequencies elicit different maximal vibrations at unique locations along the basilar membrane is referred to as the cochlea's tonotopy properties (tonotopy) (Trepel, 2015). The passing through the organ of Corti thus translates the mechanical signal into electric signals. Pressure on the hair cells causes an ion current to flow, which leads to depolarization of the membrane potential, resulting in a release of neurotransmitters (Trepel, 2015). This process stimulates the auditory nerve and triggers an action potential. The main components of the auditory pathway then take the signal to the auditory cortex. The paths from the brainstem's cochlear nucleus (CN) to the inferior colliculus (IC) cross predominantly, resulting in a higher activation on the contralateral side of the sound source input (Schnupp et al., 2011). The sound processing then passes through the midbrain and projects into the primary (AI) and secondary (AII) auditory cortical areas (Kaas & Hackett, 2000). Another important part of the auditory pathway that plays the most important role in the present work is the auditory cortex (AC) in the temporal lobe. Both hemispheres interconnect through the corpus callosum. The transmission on this processing level assures that both lobes can exchange information. The AC consists of a primary (A1) and a secondary area (primary-like). Both parts interact with other areas of higher cognitive structures, such as the frontal lobe or infratemporal structures (Schnupp et al., 2011). All major nuclei from the cochlea to the cortex have a frequency mapping (*tonotopic* or *cochleotopic*) organization (Palmer, 1995; Saenz & Langers, 2014). Tonotopically matched sites are more interconnected than non-tonotopically sites (Lee & Sherman, 2011). The primary area of the auditory cortex lies in the Sylvian fissure. Three similar areas in primates have a tonotopic organization (AI, R, RT), representing the core and a surrounding belt (secondary fields). Around this lays a third level of processing, the parabelt fields (Kaas & Hackett, 2000). The non-primary area surrounding region A1 (primary site) is Heschl's gyrus (HG). The lateral part of the HG is a crucial region where periodicity (pitch) is represented (Patterson et al., 2002). This pitch center seems to be an overlapping area of segments of the region R, A1, and a part of the belt area (Bendor & Wang, 2006). The superior temporal gyrus (STG), the planum polare (PP), and the planum temporale (PT) are located around the HG and are secondary regions.

1.2. Auditory evoked potentials and fields

In hearing-related research, various electrophysiological transient components can be measured in the auditory cortex after auditory stimulation. These auditory electrophysiological potentials (AEP) or fields (AEF) are measurable in the auditory cortex after applying acoustic stimuli to the ear and describe a series of electric changes occurring in the central nervous system, specifically in the auditory pathway. They consist of three transient electrophysiological components labeled P1, N1, and P2. Figure 1.1 shows a sample wave of the P1-N1-P2 complex. The labels of the components represent the appearance in time and polarity after stimulus onset, labeling P for positivity and N for the negativity of each peak. The following number either describes the time of appearance of the formation (e.g., 50 for 50 ms, 100 for 100 ms, 200 for 200 ms) after stimulus onset or the chronological order of potential polarity (1 for first positive or negative component, 2 for the second positive or negative component). An additional 'm' after the component name is added to the magnetic counterparts (P1m, N1m, and P2m) to differentiate it from the electrophysiological potential. The following sections will give an overview of the primary research regarding the subcomponent (N1m) in auditory processing since this is the essential component of this thesis. The N1m occurs around 60–150 ms and is followed by the P2 around 150–250 ms after stimulus onset (e.g. Crowley & Colrain, 2004; Wastell & Kleinman, 1980).

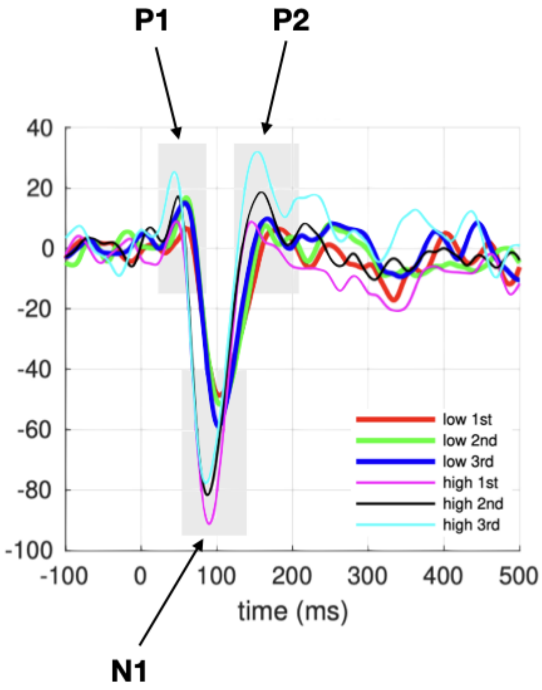


Figure 1.1.: Illustration of the P1-N1-P2 complex of a single subject measured in this study. The label "low" describes the waves elicited by the low-intensity stimuli, and "high" marks the waves evoked by the high-intensity stimuli.

1.2.1. N1m - Origins

The electrophysiological N1 response peaks around 100 ms after stimulus onset and consists of various subcomponents. The magnetic measurement of the N1 is called N1m and represents a specific supra-temporal component with a tangential orientation to the head surface. These can best be measured using MEG methods (see section 3). The following literature overview focuses on the N1m since this thesis investigates this magnetic component. The waveform N1m is relatively broad and consists of segments starting at 75 ms and ranging up to 120 ms after stimulation onset. This specific response is, therefore, rather a composition of peaks than a single deflection, which shows distinct subcomponents in a variety of different studies (e.g. Loveless et al., 1996; Nätäänen & Picton, 1987; Sams et al., 1993). These observations show the overlap and interlace of the various components over time, contributing to the measurable N1 complex. The exact origins are still controversially discussed. The literature places the generator of the electrophysiological N1 measurements in the *planum temporale* (PT). Lütkenhöner and Steinsträter (1998) also showed that the generator in the PT contributes essentially to the magnetic subcomponent of the N1 complex. The relevance of sources of middle latency components (P30, P50, P75) in the *Heschl's gyrus* (HG), which could still be active or influence the N1 amplitude is being discussed (e.g. Liégeois-Chauvel et al., 1994). Various opinions in the literature suggest that there may not be two separate generators contributing to the N1 complex but that there may be an overlap of the N1 amplitude with offsets of the middle latency components. Sams et al. (1993), on the other hand, found two separate sources of N100m components with individual recovery functions. Both components are measurable in the supratemporal cortex. Both generators are separated by approximately 1 cm (anterior-posterior direction). Here the posterior source substantially contributed to the N1m at short ISIs and reached its peak about 30 ms before the anterior origin. Loveless et al. (1996) also identified two differentiating components of the N1m response, an early posterior component ($\mathrm{N100m_P}$) and a late anterior component ($\mathrm{N100m_A}$). In their study, the dipole localization was significantly more anterior by 0.8 cm for the second component than the first, making the distinction between the two parts more apparent. Lu et al. (1992) also showed that the recovery functions of the two components are distinct. They state that the recovery cycle of the first component is in line with the approximation of the duration of auditory sensory memory measured behaviorally.

Sound intensity

Sound intensity is expressed in decibel sound pressure level (dB SPL) on a logarithmic scale to a reference pressure. Different dB SPLs were studied to identify level-depend effects. These were shown for the transverse temporal gyri (GTT or Heschl's gyri (HG)) including the PAC (primary auditory cortex) and the GTS (superior temporal gyri) (e.g. Ernst et al., 2008; Hart et al., 2003; Jäncke et al., 1998; Röhl & Uppenkamp, 2012; Woods et al., 2009). Jäncke et al. (1998) presented healthy young subjects with sounds of three different intensities (95, 85, and 75 dB (SPL)) in an fMRI study. All participants showed spread of excitation with higher intensities in the superior temporal gyrus (STG). The spatial extent increased with increasing levels of stimulus intensity, which was a robust and highly significant finding in their study. Röhl and Uppenkamp (2012) studied different intensity levels between 30 to 60 dB in their fMRI study and were also able to show a clear increase in the number of voxels activated with augmented stimulus level. Differing findings were made by Gutschalk et al. (2002) using MEG, which measured a clear effect of SPL in the PT, whereas the GTT was not sensitive to the intensity changes. This is in line with the majority of the EEG and MEG literature placing the N1 and N1m response sources in the PT (also see section 4.2).

Interstimulus interval

Additionally, researchers looked at whether the dipole locations changed when the pause between administered tones (Interstimulus interval (ISI)) was changed. Lü et al. (1992) studied short ISIs (1.2 sec) and showed that, in this case, a single dipole could account for the generation of the N100m. In contrast, at the longer ISIs (6 sec), a second component with an additional generator became measurable. This component was placed about 2 cm inferior, at the posterior temporal lobe, in contrast to the first measurement of the N100m. Sams et al. (1993) measured the N100m component using tones with varying ISIs between 0.75 and 12 sec. They fitted two distinctly measured sources at the slope's beginning and end (rising and falling parts) in the supratemporal cortex. Each was separated by 1 cm in the anteroposterior direction. This is in line with the results in the study from Loveless et al. (1996) although they could not show a lateral component as in Sams et al. (1993). Since Lü et al. (1992) showed that at short ISIs, a single dipole (contralateral in the primary auditory cortex) could represent the source of the N1m, there still was a second component active and located more inferior (auditory association areas as part of the temporal sulcus), when elongating the ISIs. This suggests that the ISI in-between stimulation plays a role in which the generator is activated and thus may play a role in how deeply the tone is processed.

1.2.2. N1m - Amplitude

The average amplitude of the auditory N1 component is directly related to the properties of the applied tone and the repetition rate of the stimuli. The following section will take a closer look at the amplitude regarding stimulus intensity and the modification with various ISIs in different stimulation paradigms.

Sound intensity

The early work of Adler and Adler (1991) showed the inverse U-shaped relationship of the stimulus intensity with a maximum at 70 dB to unattended stimuli. More recently, Soeta and Nakagawa (2012) studied the effects of different intensity levels (SPL) of sounds regarding the resulting amplitude using MEG. They were able to show an increasing N1m amplitude with increased SPLs. Their previous study from 2009 also reported an elicited N1m as the result of the stimuli onset, with a near to constant amplitude increase with increasing SPL for frequencies of 250–1000 Hz (Soeta & Nakagawa, 2009). Stufflebeam et al. (1998) applied pure sinusoidal tones using frequencies of 100, 200, 2000, 3000 Hz administered monoaurally to the right ear with 0, 5, 10, 20, 30, and 40 dB SL and reported an increase of M100 (N1m) amplitude with increasing intensity of the presented stimulus. Harris et al. (2007) also found an increase of N1m–amplitude with increasing sound-pressure levels with minimal dB differences of 2-4 dB in young adults. They also compared cortical potentials to intensity for two different frequencies (500 Hz, 3000 Hz), which showed no significant difference in the argumentation to the intensity. Another EEG/MEG study by Neukirch et al. (2002) examined the intensity dependence, using 1000 Hz tones with five different intensities (60, 70, 80, 90, and 100 dB SPL) for both the N1 and N1m components. The amplitude of the electric N1 rose with increasing intensity, whereas the N1m reached a plateau for high intensities. In their EEG study Paiva et al. (2016) applied one sinusoidal

1000 Hz tone, 70ms duration as well as different dB SPLs (45, 52, 59, 66, 73, 80, 87, 94, 100 dB SPL). The intensity dependence was analyzed both on average as well as single-trail level. Results show higher peak amplitudes with higher intensities for the N1 component in both evaluations (standard and band-pass filtered ERPs). Dimitrijevic et al. (2009) was studying a continuous tone with three different frequencies (250, 1000, and 4000 Hz) and an intensity change which varied from 0, 2, 4, 5 and 8 dB above the 80 dB SPL continuous tone. The results also showed an increase in amplitude for the cortical potential.

Interstimulus interval

It has been widely shown that the response amplitude increases progressively as the ISI increases. Hari et al. (1987) demonstrated that the amplitude increased as the ISI was raised from 1 to 9 sec. This is also referred to as the *"temporal recovery function"* (Nätäänen & Picton, 1987). In the study of Loveless et al. (1996), the N100m$_\mathrm{A}$ showed a clear enhancement to the second tone when tone pairs were presented with intervals less than 250 ms between the tones. There are various studies, which show larger N1 amplitudes at variable rates of stimulation with time intervals shorter than 400 ms in respect to slightly longer intervals (400-600 ms) (e.g. Budd & Michie, 1994; Loveless et al., 1996; Sable et al., 2003). The N1m response increases with increasing ISI (Sams et al., 1993). In the same study Sams et al. (1993) differentiated between the posterior component (N100m$_\mathrm{P}$), which attenuated up to 6 sec ISI and then stayed at the same amplitude height. The anterior component (N100m$_\mathrm{A}$), which in contrast, continued its amplification up the 12 sec ISI.

On the other hand, W. Ritter et al. (1968) showed early on that a decrease of amplitude could be measured concerning a repeated stimulus if there is a relatively long period without stimulation (8000 – 12000 ms) in between the repeated paired clicks. This is true if the paired clicks are separated by a short time interval (500 ms). The decrease could be measured for all AEP components (P50, N100, and P200) and shows an amplitude reduction regarding the second tone for the electrophysiological and magnetic measurable N1 component. But there are also diverging results, which show an asymptotic decrease (EEG: e.g. Fruhstorfer (1971), W. Ritter et al. (1968), and Woods and Elmasian (1986)). Rosburg (2004) suggests that the ISI within the trains can be held accountable for this effect. It seems more likely for the amplitude to decrease asymptotically at longer ISI. But overall, the majority of the literature reports a decrease that reaches the lowest amplitude by the second presentation of the stimulus with the following tones staying at this amplitude level (EEG: e.g. Barry et al. (1992), Budd et al. (1998), and Rosburg (2004), MEG: e.g. Rosburg (2004) and Sörös et al. (2006, 2009)).

1.3. Dynamic range adaption – Habituation vs. Recovery approach

Two explanations are currently discussed regarding the decrement of the response after repetitions of stimuli: one side interprets this mechanism as a simple form of *learning* (habituation process), whereas the other side refers to the involvement of the central nervous system cell assemblies, which means that it is an effect of *refractoriness* or stimulus-specific adaption (e.g. Budd et al., 1998; Pérez-González & Malmierca, 2014).

The learning approach, which is discussed in the literature is using the latent inhibition model. The process of habituation needs to fulfill specific criteria such as an asymptotic response decrease, a mechanism of dishabituation, and a stimulus specificity (e.g. Rankin et al., 2009; Thompson & Spencer, 1966). This model suggests that the N1 response should be the same regardless of the given onset latency and the stimulus onset asynchrony (SOA) presented. It infers that the latent inhibitory process should be fully operating by 400 ms. Sable et al. (2004) were able to show that regardless of the number of stimuli presented, the N1 amplitude decreased in response to tones that were administered up to 300 ms following the onset stimulus of the tone train. In this study, they observed two different patterns within the curve. The N1 amplitude decreased in response to the stimuli between 0–400 ms after train onset. Then this was followed by maintenance of the amplitude for latencies after 400 ms from the onset. The latencies before and after 450 ms differed significantly. McEvoy et al. (1997) used tone pairs in their studies, and they also proposed a model in which an inhibitory process is responsible for the attenuation of the N1 component. In this approach, they assumed that the N1 generator spreads the activation to neurons, giving feedback to the N1 generator and leading to an inhibitory response of the subsequent N1 component. The assumption was that the sounds which occur before the complete inhibition response is finalized are less attenuated.

The recovery approach explains the decrement of the component as a refractory process in cell populations. Budd et al. (1998) states in his study that the neural population that generates the N1 becomes refractory after the first response, and this leads to the reduction of the second peak. This model thus proposes that the neuronal response is diminished immediately after the first response and gradually recovers if no further tone is played. If two stimuli rapidly follow each other within a brief interval, the responding neural population does not have enough time to recover fully. In this case, the impact on the second stimulus (lower amplitude) is affected. If the time interval between the stimulus onsets increases, the neuron has more time to return to its resting. The amplitude will return to the beginning stage and be fully reset before the next stimulus arrives. This means that if one stimulus follows directly after the next, the resetting of the resting state is not finalized, which leads to the refractory property of the neurons with an ongoing attenuation keeping the N1 at a minimum (e.g. Pérez-González & Malmierca, 2014). Sable et al. (2004) also found that an increase in the time interval between the individual tones of the train should result in the response being less attenuated because there is more time for the generators of the N1 to recover.

1.4. Musicality in early cortical processing

Tone stimuli presented in a sequence establish expectations resulting in anticipation of the coming stimuli. The participants rely on both, statistical learning and prior knowledge for these predictions (Morgan et al., 2019; Pearce, 2018). A comparison between musicians and non-musicians has shown increased amplitudes of the AEP and AEF responses (Kuriki, 2006; Pantev et al., 1998; Shahin et al., 2005). This difference, resulting in higher amplitude and a decrease in latency, was thought to indicate higher synchrony and stronger neural connections (Tremblay et al., 2001). Baumann et al. (2008) specifically looked at the enhancement of the auditory-evoked potentials of musicians under the scope of expertise and selective attention. The results showed that musicians' increased N1 peak potentials could be replicated, and the effect of selective attention resulted in a distinctly different topography and time course. These studies support the view of musicians' enlarged neural responses (AEPs) for specific sound features and thus show evidence for the main effect of enhancing the N1 component of the AEP/AEFs, which is the investigated component in this thesis. However, there are several other MEG and EEG studies that showed an increased response to musical tones in contrast to sine tones in non-musicians as well (e.g. Lütkenhöner et al., 2006; Shahin et al., 2005). Andermann et al. (2021) looked at the responses of musical experts regarding the transient responses to pitch-onset as well as the subsequent transitions to explore whether they show more response suppression. The results reported stronger f_0 -related AEFs, as well as stronger differences to the fixed vs. variable sequences, in musically skilled participants. This finding suggests a strong influence of adaptive mechanisms in cortical pitch processing, which might be modulated by the listener's prior musical knowledge and experience. The recent review of Sanju and Kumar (2016) gave a broad overview of the literature, which showed that the evidence predominantly speaks for enhanced auditory potentials in musicians. Studies showed enhanced AEPs for musicians from the brainstem to cortical levels and increased attentive and pre-attentive skills in contrast to non-musicians.

1.5. Test of musicality – AMMA

To measure the musical aptitude of the participants, the *Advanced Measure of Music Audiation* (AMMA) test (Gordon, 1989) was applied in this study. Musical aptitude is the individual's ability to accomplish objectives in music. It is a well-established assessment in Western music education schools to detect students with special musical aptitudes. It can also be used to determine the evaluation and prediction of musical achievements. The AMMA is a test for stabilized music ability that measures two different dimensions, *tonal* and *rhythmic*.

For the AMMA test, there are three sample norms available (music major students at the university level, non-music students at the university level, and high school students). These norms are based on the musical age since the differences in chronological ages within these groups are so small that there is no need for separate norms regarding chronological ages (Gordon, 2004). Over time, AMMA has proven to be a valid and reliable instrument to measure the stabilized music aptitude (Gordon, 1989). The split halves reliability coefficients (r_{sh}) are based on the entire sample of each norm group of the standardized test and lie between 0.81 and 0.88 for the *total* score, between 0.80 and 0.85 for the *rhythm* subtest and between 0.80 and 0.84 for the *tonal* subtest (Gordon, 1989). The retest reliability (r_{tt} for non music majors) lies between 0.83 and 0.89 for the *total* score, between 0.81 and 0.87 for the *tonal* subtest and between 0.80 and 0.86 for the *rhythm* subtest. All these values confirm sufficient reliability for the musical aptitude test. The intercorrelations of the subtests (R and T) are also high (0.72 and 0.78). The test scores are immune against maturation after the age of nine as well as musical instruction and practice (Gordon, 2004; Gordon, 1989).

The longitudinal predictive validity of the test has been shown in the accompanying manual as well as in the publication from (Gordon, 1990). The correlation between the judges' rating of all the dimensions combined of the students' etude and the AMMA scores of the study from Gordon (1990) is presented in the table below.

Table 1.1.: This table shows the judges' evaluations of the students' etude achievement of all the rating dimensions combined and the AMMA scores (Gordon, 1990, p.10).

	Judges'		
AMMA	1	2	3
Tonal	.74	.76	.70
Rhythm	.71	.74	.69
Total	.80	.81	.76

Note. N=114

1.6. Magnetoencephalography

Single-sensor Magnetoencephalography was first used to record magnetic brain activity data in the late 1960s (e.g. Cohen, 1968). The MEG has a high sensitivity to a broad spectrum of fast brain signals as well as an enhanced ability to map anatomical locations (Baillet, 2017). It is a non-invasive method to record cortical magnetic fields of the whole brain with a sub-millisecond temporal resolution (e.g. Baillet, 2017; Gratta et al., 2001; Hämäläinen et al., 1993; Körber et al., 2016).

The examined magnetic fields represent the synchronized activity of a group of more than 10,000 to 50,000 activated cells in a particular cortex area. This activity widely represents the excitatory and inhibitory postsynaptic potentials of the large pyramid cells of the cortex. The pyramid cells and their ionic currents are the main contributors to MEG signals since they are usually locally aligned next to each other and are arranged perpendicular to the cortical surface (e.g. Baillet et al., 2001; Hämäläinen et al., 1993; Kaufman et al., 1981; Murakami &

Okada, 2006). The postsynaptic dendritic transmembrane current is caused by the presynaptic neurotransmitter release, resulting in a local field potential (LFP) at the dendrite and soma. The intracellular current flow along the neuron axis induces an extracellular return (volume) in the opposite direction on the outside of the neuron (Lopes da Silva, 2013). The intra-cellular current flows need to have a similar orientation so that the generated magnetic fields add up to a large enough field strength to become measurable by the sensors outside of the head (e.g. Gross, 2019; Hämäläinen et al., 1993). The vertical pyramid cells aligned with the cortical surface generate a field that can be measured extracranial. Thus, sources within the sulci become measurable with the MEG (Zschocke & Kursawe, 2012). This is a distinct feature of the method MEG and a reason why it is often used in auditory research. Another reason is that the frequency band of the MEG signal lies between 0.5 - 1000 Hz, where the most commonly used bandwidth is 1 - 8 Hz (Lopes da Silva, 2013).

A special sensitive sensor is needed to capture the still very low pronounced activity (50–500 fT) outside the scalp. These detectors are called SQUIDs (superconducting quantum interference devices) and possess the property to become superconductors when cooled to about 4.3 ° K (e.g. Baillet, 2017; Cohen, 1972; Körber et al., 2016). The neuromagnetic field induced on the SQUID is likewise a flow of electrons. The phase difference in the waveforms of the flow in the SQUID is the measured signal, which is directly related to the magnetic field strength produced by the cortical source. The MEG measurements are a magnetic induction of the vector signal of the electrodynamics, which means they depend on the location and orientation of the pick-up coils regarding the intracerebral source. This is very important because the further they lay apart, the weaker the magnetic field. This shows the divergence from EEG, where differences between the scalar potential of the electrodes are measured (e.g. Baillet, 2017; Cohen, 1972; Körber et al., 2016). The magnetic signal picked up by the MEG is apprehended outside the head and does not need a reference electrode. It shows a high insusceptibility against non-cerebral muscular activity and is not affected by the cranium, the cornea, and cerebrospinal fluid. On the other hand, the MEG is less sensitive to measuring sources that have a radial orientation regarding the cortex surface because they are aligned parallel to the SQUIDs (Baillet et al., 2001). The sources on the cortical surface provide a measurable MEG signal that is up to 100 times stronger than those generated by subcortical structures (Attal et al., 2009; Hillebrand & Barnes, 2002). MEG technology is highly sensitive and thus needs a specific shielded surrounding from outside electromagnetic sources such as moving metal objects or electrical powered instruments which create strong magnetic inductions (e.g., traffic, elevators, computers). A 20-ton, multilayered shielding room to shelter the MEG remains the best resolution guard for the MEG to this day (Baillet, 2017).

1.7. Source analysis

Dipole source analysis is a method to examine dipoles representing circumscribed cortical areas of activity. The dipole sources do not change their orientation and location, but their activity over the period measured. For the auditory sources measured by MEG, one tangential-oriented dipole is usually placed in the auditory cortex, representing the main generator of the N1m activity. The placement of the dipole source is found by using an iterative process optimized to the lowest residual variance (RV, variance of the measured data unexplained by the model). The forward/inverse problem needs to be solved to find the optimal location.

To resolve the forward problem, the modeled source of the magnetic fields is placed at known approx brain locations that pick up a current with available location and orientation in a prespecified model. The magnetic fields of a spatially extended flow are also computable using these elementary sources as a linear superposition of the magnetic fields (Gross, 2019). To achieve this, there needs to be empirical knowledge and a hypothesis about functional anatomical networks lying beneath the scalp surface. Maxwell's equation needs to be approximated to solve the forward problem. The dipole's spatial location and the surrounding tissue's conductivity are approximated. The field potential of the complex dipole setup arises from the linear Maxwell's equation through superposition. The spatiotemporal analysis determines the activity's location and the activity curve (waveform). This is done by separating overlapping potentials at the scalp surface (e.g. Gross, 2019; Ilmoniemi, 1993; Scherg & Von Cramon, 1985; Scherg, 1991). This head model thus solves the forward problem at the known sensors for a single small current segment at a specific location and orientation. The results are called equivalent current dipoles that specify the source areas, which are evaluated (e.g. Gross, 2019; Hämäläinen et al., 1993). The dipole represents the center of the active cortex area (the primary current). The temporal course of the dipole represents the activity of the period measured. The source analysis method is thus used to derive the sum activity from all the measured waveforms. These have to be deducted out of the noisy signals of the whole measurement through the separation of overlapping potentials at scalp level (Scherg, 1991). Considering the *a priori* measurement error is also important in this approach. It is only possible to have as many sources as waveforms collected by the SQUIDS sensors (Scherg, 1990). The use of a simplified head model thus makes it possible to approximate the spreading of the potentials at scalp level (Rush & Driscoll, 1968). The head model's construction specifies the tissue conductivities' spatial properties. A template can be used for the model, or an individual anatomical MRI can be computed. In this study, a spherical model was applied.

The next step involves solving the inverse problem by identifying the location and orientation of the electromagnetic currents about the recorded magnetic field (e.g. Gross, 2019). The inference from the measured data at the scalp does not allow a conclusion about the source location within the cortex. Helmholtz (1853) already stated in 1853 that it is not possible to directly conclude where the origin of the current lies from outside of a conductive medium through the magnetic fields measured outside of the scalp (inverse problem). Thus, the solution to the inverse problem is the recalculation of the underlying source configurations. This makes use of the relationships that are computed by solving the forward problem and attempt to pinpoint the locations and orientation of the dipoles in the brain that best account for the measured magnetic field (e.g. Baillet et al., 2001; Gross, 2019; Wipf & Nagarajan, 2009). An iterative process computes the calculation of the equivalent dipoles. One or more active sources are placed inside the head model, and the simulated data is then compared to the measured data. The sources are shifted until the best fit is reached. This fitting process is a hypothesis-testing method. In the modeling procedure, the dipoles are always placed at the origin where the log data's variance is greatest. The reduction of the data information enables a higher signal-to-noise ratio. When symmetrization for the dipoles in the left and right hemispheres is used, even greater stability can be reached. The classic approach is a multi-dipole model, which explains the measured data by typically less than ten equivalent dipoles. For further information about the software, see section 3.4.

2. Research questions

Looking at the literature on neurophysiological research of AC, the N1m is a well-examined component. (see section 1.2.2). The study aimed to replicate the known effect of the interstimulus interval and amplitude variation effect as well as to look at the dynamic range adaption of the N1m component. Within the field of auditory studies, only a few research questions looked at the relationship between musicality and its impact on the N1m component. To fill this gap, another part of the study addressed this question. For this purpose, the musicality score (AMMA) was calculated using a validated test procedure (see section 3.3.1) and then set in relation to the measured N1m results.

2.1. Hypothesis – N1m

The first aim of the study was to replicate the known N1m effects of the intensity-modulated stimuli, which are presented with different interstimulus intervals (ISIs) (e.g. Rosburg, 2004; Sörös et al., 2006, 2009).

Amplitude Modulation The examination of the intensity-modulation of the N1m component intended to replicate the known stable effect shown in various studies of tone-modulated auditory stimulation setups. This analysis should also show the known intensity-modulation effect for the different ISI conditions.

> **H1–1:** The low-intensity-modulated stimuli will result in a lower N1m amplitude compared to the high-intensity-modulated stimuli.

Interstimulus Interval It is known that with increasing the ISI, the amplitude of the N1m component also increases (e.g. Hari et al., 1987; Sams et al., 1993). For this part of the study, the intention was to replicate this effect.

> **H1–2:** The increasing ISI will result in a higher N1m component for both high and low-intensity-modulated tone stimuli.

2.2. Hypothesis – N1m & Dynamic range adaption

The research question of this part of the study was to examine the effects of dynamic range adaption (e.g. Rosburg, 2004; Sörös et al., 2006, 2009) regarding the intensity levels of the stimulus as well as the impact of differing ISI conditions.

Amplitude Modulation Since the majority of the literature shows a decrease in the amplitude of the second tone presented, this part of the study tried to replicate this effect. Yet there has not been a comparison of the adaption effect between different intensities of stimuli applied. This part of the thesis is aimed at closing this gap.

> **H2–1:** The first intensity-modulated tone (high and low) will show a higher N1m amplitude compared to a second and third intensity-modulated stimulus.

Interstimulus Interval In line with the literature (e.g. Rosburg, 2004; Sörös et al., 2006, 2009), we expected to reproduce the effect that the adaptation will not be present for more extended ISI conditions. This would be evidence for the postulated recovery function (see section 1.3).

> **H2–2:** There will be a decrement of the N1m amplitude between the first and the second tone, which will last throughout the subsequent third tone of a fixed consecutively presented amplitude tone train in the condition of 1000 ms ISI. This short-term adaption effect is observable within the high and low amplitude modulation stimulation.

2.3. Hypothesis – N1m & Musicality

The research on the relationship between the N1m component as well as AEF and musicality mostly shows an increased component for participants with musical training and professional musician (e.g. Andermann et al., 2021; Sanju & Kumar, 2016). This part of the study aimed to examine the effects of the N1m component by non-professional-musician with higher musicality scores on the AMMA test of musicality and, in the second step, investigate if these effects change with the differing ISI conditions.

Amplitude modulation & AMMA score Following the literature, this part of the study should replicate the higher N1m for the group of participants with high AMMA values (e.g. Kuriki, 2006; Pantev et al., 1998; Sanju & Kumar, 2016).

> **H3–1:** There will be an increase in the measurable N1m amplitude for the high AMMA score group in contrast to the low AMMA score group.

Interstimulus Interval & AMMA score This analysis aimed to look at the N1m responses regarding the different ISI conditions and the AMMA scores the participants reached. There are no studies known that have analyzed the relation between the ISI effects and musicality (to the author's knowledge).

> **H3–2:** There will be an increase in the measurable N1m amplitude for longer ISI for both groups (high and low AMMA scores), where the high AMMA score groups elicit a higher N1m response.

2.4. Hypothesis – N1m & Dynamic range adaption & AMMA score

Regarding the basis of the examined N1m attributes, the next step was to look specifically at the dynamic range adaption (e.g. Rosburg, 2004; Sörös et al., 2006, 2009) of the component and the AMMA score groups. The main scope of dynamic range adaption focused on N1m effects. Up to now, the relationship between the dynamic range adaption and musicality scores has not been investigated. The following hypothesis aims to explore this.

Amplitude modulation & AMMA score This part of the study investigates the relation between intensity modulation, specifically the dynamic range effect of the N1m component and the AMMA score groups (musicality).

> **H4–1:** There will be a significant increase in the measurable N1m amplitude between the first to second and third stimulus tone for participants with high AMMA scores.

Interstimulus Interval & AMMA score The last hypothesis investigates the connection between the different ISI conditions and the two AMMA score groups as well as the dynamic range adaption effects within the intensity-modulated-high and -low stimulus tone groups. Until now, this connection has not yet been looked at. The following hypothesis states what was expected based on the previously reviewed literature on ISI, musicality, and dynamic range adaption.

> **H4–2:** There will be a significant increase of the measurable N1m amplitude within the different ISIs, the tone sequences, and between the high and low AMMA score groups.

3. Material and methods

The following section focuses on the examination methods used in these studies for a better understanding of the measurements reported. First, an insight into the sample of participants is given, followed by information about the stimuli applied. Next, a detailed description of the data acquisition is presented.

3.1. Participants

30 adult listeners (15 women, 15 men, mean age 31,5 ± 10,7 years) volunteered to take part in the experiment. We recruited a larger than the usual number of participants in order to improve statistical power as suggested by Button et al. (2013). Subjects provided written consent prior to the examination. Participants did not report any history of hearing impairments or any psychiatric or neurological disorders. All volunteers were a priori tested for normal hearing abilities (see section 3). The experiments were carried out within the framework of the *DFG-Grant „Dynamic range adaptation in chronic tinnitus*" which was approved by the ethics committee of the Medical faculty of the University of Heidelberg (S-419/2014 to PD Dr. André Rupp). The participants in this experiment were all recruited, instructed, and measured by me.

3.2. Stimulation

All stimuli were generated using MATLAB (Version 9.8.0.1451342, R2020a, Natick, Massachusetts: The MathWorks Inc.). The stimuli for the study were intensity-modulated sine tones with a carrier frequency of 1131 Hz, which were administered monoaurally to the left ear. Figure 3.1 illustrates the carrier frequency, which was then modulated in intensity. For the tone sequences, there were three conditions with an ISI of either 1000 msec, 2000 msec, or 4000 msec and each lasted for about

30 min. The stimuli tones were paired to trails of three sine tones of 44 dB SPL (250 msec duration) and 62 dB SPL (250 msec duration) each. Figure 3.2 shows the repetition order of the three low 44 dB SPL and three high 62 dB SPL tones schematically. To ensure that there is no confounding effect, the order in which the ISI conditions were administered, was semi-randomized between participants (see Table 3.1). During the study, participants watched a self-chosen movie with subtitles presented without the soundtrack in order to maintain vigilance throughout the experiment. In-between conditions, participants had the chance to take a 5 to 15 min break.

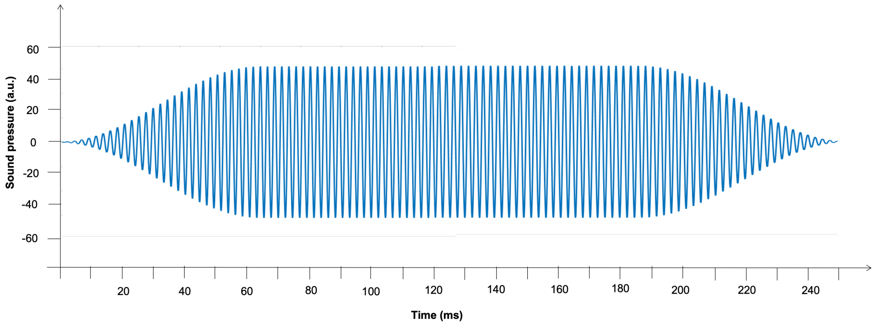
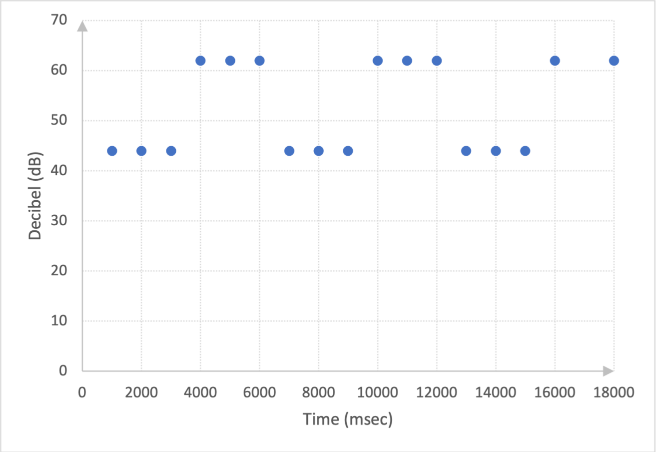


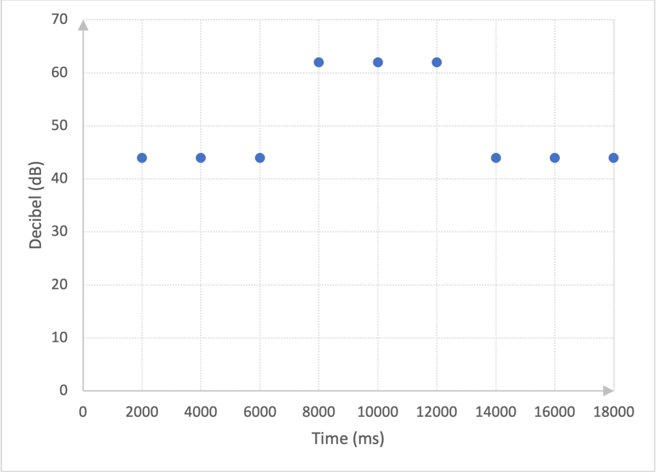
Figure 3.1.: The graphic illustrates the carrier frequency of 1131 Hz of one 62 dB SPL stimulus tone.

Table 3.1.: All conditions were presented in semi-randomized order as outlined in this table. The three conditions each lasted about 30 min and were presented consecutively to each participant with a short break between sets of about 5-15 min.

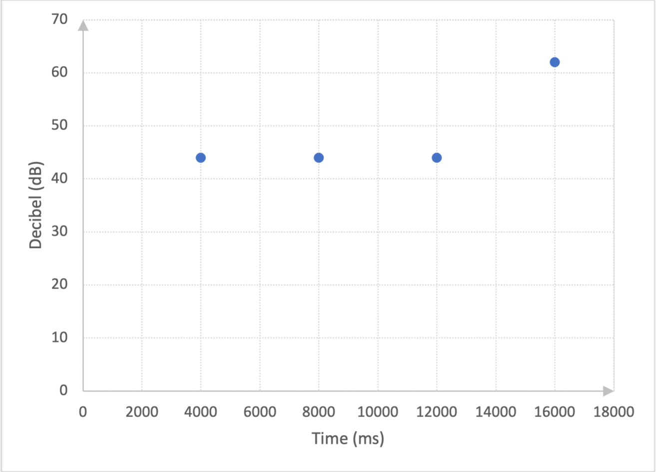
Participant-Nr.	Presentation order (Condition of ISI msec)
1, 7 ,13 ,19 ,25	1000, 4000, 2000
2, 8, 14, 20, 26	1000, 4000, 2000
3, 9, 15, 21, 27	2000, 1000, 4000
4, 10, 16, 22, 28	2000, 4000, 1000
5, 11, 17, 23, 29	4000, 1000, 2000
6, 12, 18, 24, 30	4000, 2000, 1000



(a) Sample section of condition ISI 1000ms



(b) Sample section of condition ISI 2000ms



(c) Sample section of condition ISI 4000ms

Figure 3.2.: Illustrated in these graphics are sections of the repeated stimulus sequence of the 44 dB SPL and 62 dB SPL tones over time. Each tone, which is here shown schematically, was 250 ms long.

3.3. Data aquisition

3.3.1. Audiometric & Musicality testing

For audiometric testing, a Hammerfall DSP Multiface System, as well as Sennheiser, HAD 200 (Sennheiser GmbH, Wedemark-Wennebostel, Germany) closed dynamic headphones were used, which reaches ambient sound insulation of approx. 30 dB. A custom-made MATLAB function was used to asses audiometric thresholds.

To determine the hearing threshold, the tones were administered monoaurally. First, starting with the left side, the absolute threshold of the hearing was determined for twelve frequencies. The presentation then switched to the right side using the same frequencies for stimulation between 0,125 kHz and 15 kHz in terms of dB hearing level (dB HL). Every response was marked on the individual control sheet. Test results were then screened for pathological outcomes. If the results were non-pathological, the testing continued with the AMMA application.

For the musicality testing, the AMMA test was administered, which consists of 30 music melodies, each item featuring two musical sequences, which are presented with a short pause in between. Tonal and rhythmic dimensions are included in one test run. Each musical item only differs in either the tonal order, the rhythmic dimension, or not at all. Right after the administration of two sequences, the participant is asked if the two presented parts are identical or different in regard to tonality or rhythm. The discrepancies in tonality and rhythm can be set at any given point of the sequence. The possible choices are limited to the same, different in tonality, or different in rhythm. The orders of the items are randomized (Gordon, 1989). The whole test takes about 20 minutes in total. A maximum of 80 points can be reached, with 40 points on the subtest for the tonal and rhythmic dimensions. Studies were able to show that the test is able to differentiate between professional and non-profession musicians (Schneider et al., 2002, 2005). High scores imply high musical aptitude. Following these results, the AMMA was used as an instrument to measure the stabilized musical aptitude of the participants in this study. The participants were divided into two clusters by calculating a median split resulting in a dichotomization with a separate group for high vs. low AMMA scores.

3.3.2. MEG measurements

To record the neuromagnetic responses a Neuromag-122-wholehead-MEG-System (Elekta Neuromag Oy, Finland; (e.g. Ahonen et al., 1993)) that was installed in 1996 at the University Clinic in Heidelberg (Department of Neurology, Section Biomagnetism) was used. The MEG is located in a shielded room, which was mounted by IMEDCO AG, Hägendorf, Switzerland. It has 61 planar gradiometers inside the MEG dewar. These are arranged in a cross-like figure eight position paired with a SQUID inside the hood. Before placing the test subject under the MEG dewar, additional four head-positioning indicator coils (HPI) have to be adhesively applied onto the head (Coil 1: mastoid bone right, Coil 2: forehead right, Coil 3: mastoid bone left, Coil 4: forehead left). Additionally, the position of the nasion, the preauricular points, and 100 additional surface points are digitalized using a 3D pen (Polhemus Inc., Vermont, USA) in order to determine the head position relative to the MEG dewar. During the recording, the analog signal was low-pass filtered at 330 Hz, high-pass filtered at 0.03 Hz, and digitalized at a sampling rate of 1000 Hz. The sound system through which the stimuli were generated consisted of a 24-Bit-Soundcard (ADI 8DS AD/DA; RME Audio AG, Haimhausen, Germany) and an attenuator (PA–5 und HB–7; Tucker-Davis Technologies, Inc., Alachua, Florida, USA) attached to a headphone buffer. The sounds were delivered by Etymotic ER3 earphones through a plastic tube (97 cm) with foam tips to the left ear only. Participants were instructed to ignore the auditory stimulation while watching the self-chosen movie with subtitles.

3.4. Analysis procedures

The analysis started with the evaluation of the neuromagnetic data using BESA® software (Version 5.2; Gräfelfing Germany). The next step consisted of computing the results of the psychometric information collected (AMMA test) to divide the groups of musicality levels. The last step included further analysis of the evoked data and statistics of the data sets using Statistical–Analysis–System (SAS Version 9.4; SAS Institute, Cary NC). The next paragraphs give a detailed insight into the procedures used.

The analysis procedure of the magnetoencephalographic data started by applying an artifact correction of the raw data by visual inspection and the built-in automated rejection tools using BESA® software (Version 5.2; Gräfelfing Germany). Then, noisy channels and epochs were discarded when amplitudes exceeded >±8,000 fT cm or gradients >±800 fT cm. The remaining sweeps were averaged into segments of interest for each tone stimulus and each participant. To model the N1m for this experiment the BESA® spatiotemporal source model was used (see section 1.6) (e.g. Scherg, 1990). The source localization model uses equivalent current dipoles of each participant. This method compromises the spatial information of the dipole and its physiological activity over time. In this experiment, a source model with two dipoles, one dipole in each hemisphere, was generated for each participant individually. A symmetry constraint was used on data sets where necessary to stabilize fits. Furthermore, a principal component analysis (PCA) was applied to compensate for drifts if needed (Berg & Scherg, 1994). The PCA generates a component that explains the most variance in the model of that specific drift or artifact. The dipole fits for the N1m component were based on unfiltered but artifact-corrected averages for each condition's »Grand Average all Condition«data (1000 ms, 2000 ms & 3000 ms). Afterward, each participant's grand average dipole fit (conditions pooled - 1000 ms, 2000 ms, 4000 ms) was applied to the individual averages of each tone stimulus (t1, t2, t3, t5, t6, t7) and the source waves were extracted separately for all conditions and stimuli.

The analysis of the audiometric data collected by applying the AMMA test was calculated for each participant's tonal, rhythmic, and total scores based on the manual. The evaluation of the AMMA test results determines the correct and incorrect answers for each category (correct: Rhythm R_1 as well as Tonality T_1 & incorrect: R_2 as well as Tonality T_2 and sums these up separately. Then the incorrect answers are subtracted from the correct solutions and added to an absolute term of 20 (to avoid negative outcomes). The outcome is an adjusted value ξ for each category *rhythm* and *tonality.* The total test score ξ_{total} is calculated by adding the *rhythm* and *tonality* scores.

$$\xi_{\text{rhythm}} = R_1 - R_2 + 20 \tag{3.1a}$$

$$\xi_{\text{tonal}} = T_1 - T_2 + 20 \tag{3.1b}$$

$$\xi_{\text{total}} = \xi_{\text{rhythm}} + \xi_{\text{tonal}} \tag{3.1c}$$

The sub-scores can reach 40 points, adding up to 80 points, which can be achieved in the overall score. When examining the sub-scores, a spread of two or more points can be interpreted as an actual distinction (Gordon, 1989) (for further information, see section 4.1). In the last step, a median split based on the total AMMA score of the participants was computed to generate two groups that distinguish between low and high AMMA values.

For the statistic evaluation procedure, a repeated-measures ANOVA was calculated for the different variables using the Statistical–Analysis–System (SAS Version 9.4; SAS Institute, Cary NC). First, the peak was detected for each of the two dipoles, and then an additional +/- 25 ms window was added on each side of the peak. This resulted in a 50 ms interval, which was then used for further assessment of the N1 amplitude. The defined ANOVA factors included the ISI, brain hemisphere, as well as stimulus intensity, and musicality. Then F-tests and p-values were calculated for the main factors as well as for the interactions. Further statistics can be found for reference in Appendix A (mean values, standard deviations, lower and upper 95% confidence interval, additional statistics for 1000 ms vs. 2000 ms and 2000 ms vs. 4000 ms ISIs).

4. Results

The first section shows the results of the grouping of participants in regard to the *Advanced Measure of Music Audiation* test, followed by the evaluation of the MEG data collected.

4.1. AMMA

For each participant, the calculation yielded individual values for all AMMA test dimensions (for analysis procedure, see section 3.4). These are shown in table 4.2. To establish groups with high and low musical aptitude characteristics, the participants were assigned to each group based on the study of Andermann et al. (2021). The median overall AMMA score divided the participants into a low AMMA score group (≤ 55 points) and a high AMMA group (> 55 points), resulting in two groups of 12 and 15 participants for high and low musical aptitude groups (shown in table 4.1).

Table 4.1.: The table shows the statistical characteristics of the 27 participants assigned to the two AMMA score groups representing high and low musical aptitude.

	AMMA Groups	
	High	Low
Mean	62.67	49.60
SD	4.44	3.70
SE	1.28	0.96
n	12	15
	n = 27	

Table 4.2.: This table shows the results of the AMMA scores reached by the 27 participants included in the evaluation. The order of participants is arranged according to the group they were assigned to.

Nr	AMMA *tonal*	AMMA *rhythmic*	AMMA *total*	AMMA group assignment
1	22	24	46	1
2	21	21	42	1
3	23	23	46	1
4	26	27	53	1
5	24	25	49	1
6	22	27	49	1
7	27	24	51	I
8	24	31	55	1
9	23	25	48	1
10	23	25	48	1
11	24	23	47	1
12	23	30	53	1
13	24	25	49	1
14	24	29	53	1
15	24	31	55	1
16	31	34	65	2
17	29	30	59	2
18	32	34	66	2
19	29	29	58	2
20	31	35	66	2
21	28	31	59	2
22	33	33	66	2
23	34	34	68	2
24	34	33	67	2
25	27	29	56	2
26	31	34	65	2
27	28	29	57	2

4.2. N1m

All BESA® (Version 5.2; Gräfelfing Germany) models were computed with the two dipole model, which was fitted for the »Grand Average all Condition« and then applied to the different datasets (each individual ISI condition).

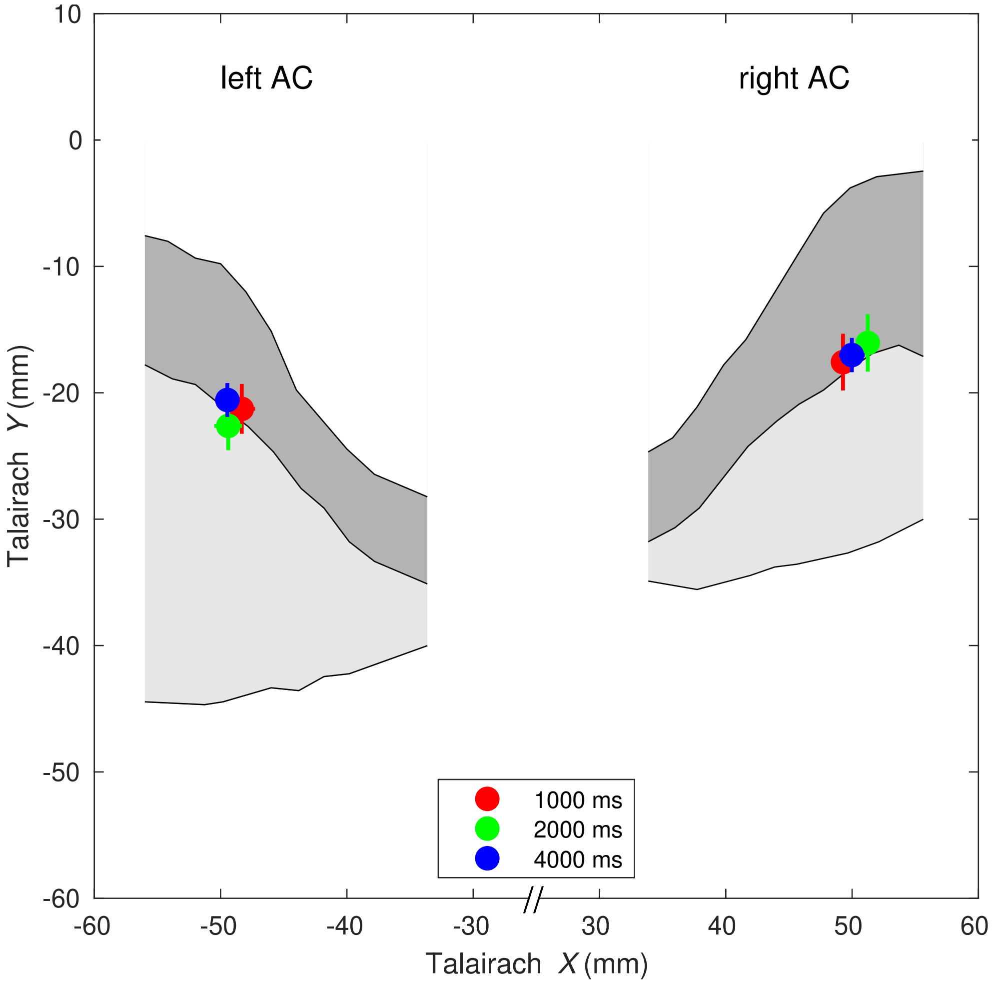


Figure 4.1.: The projection of the mean dipole coordinates onto the atlas of Leonard et al. (1998) shows in both hemispheres a position close to the boundary between Heschl's gyrus (dark shaded area) and the planum temporale (light shaded area). The error bars represent the standard error of mean. The subsequent transfer of these positions to the fsaverage brain (Dale et al., 1999) with the HCMMP1 atlas (Glasser et al., 2016) shows that on the left side all positions are to be assigned to the lateral belt. In the right hemisphere, the coordinates for the 1000 ms and the 4000 ms condition are also in the lateral belt. In the case of the 2000 ms condition, the middle position corresponds to the P-belt area. Thus, all generators of this BESA model can be attributed to the planum temporale.

The columns in the figures show the brain waves measured by the dipole in each hemisphere (left/right). The next section shows the results regarding the studied hypotheses, the statistics, the amplitude modulation, and the waveform amplification with respect to the different interstimulus intervals (ISIs). In each section, the figures show different grand averages computed together to reach a higher signal-to-noise ratio for the particular research question. For in-depth analysis procedures using BESA®, the applied fitting procedure, and statistical methods, see sections 3.4.

4.2.1. H1-1 – Amplitude Modulation

To compare the low vs. high intensity-modulated tones, all ISI conditions were pooled together to raise the signal-to-noise ratio. The statistical analysis in this part shows differing results (see table 4.3). For the intensity-modulation, the test shows a significant difference for the »Grand Average All Condition« between the groups high- vs. low-intensity modulation, $F(1{,}25) = 46.06$, $p = <.0001^{**}$. This is in line with H1-1, the hypothesis can be accepted. For the same grand average, the analysis of the hemisphere effect calculated did also yield a significant effect, $F(1{,}25) = 18.37$, $p = <.0002^{**}$. The ANOVA with repeated measurements yielded a significant but smaller effect for the interaction of intensity and hemisphere, $F(1{,}25) = 7.06$, $p = <.0135^{*}$.

Table 4.3.: Statistical Analysis N1m – Amplitude Modulation

Source	df	F-Value	p-Value
Intensity	1, 25	46.06	$<.0001^{**}$
Hemi	1, 25	18.37	0.0002^{**}
Intensity*Hemi	1, 25	7.06	0.0135^{*}

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, Hemi = hemisphere

The visual inspection of the high-intensity-modulated stimuli (purple line) shows a noticeable higher peak regarding the low-intensity-modulated tones (mint line). This result is in line with H1-1, where a higher N1m was postulated for the high-amplitude modulated tone vs. the low-modulated tone. The contralateral side of

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Note. * p-Wert $< .05$, ** p-Wert $< .01$

stimulation shows a more pronounced peak of the N1m for the high tone condition than the ipsilateral side. In contrast, the distinction between hemispheres for the low-intensity-tone stimuli is noticeably smaller.

Figure 4.2.: This graphic shows the grand averaged data in response to low- vs. high-intensity-modulated tones in the left and right hemispheres (left & right columns).

4.2.2. H1-2 – Interstimulus Interval

The investigation of different interstimulus intervals, figure 4.3 shows intensity-modulated tones grouped, but separated for ISI condition. As the ISI increases, the amplitude increases noticeably. The statistical analysis for the ISI conditions followed the same procedure as described in the methods section (see 3.4). Table 4.4 shows the overview of all outcomes for the interaction effects for the ISI, which were studied for this hypothesis. For the ISI conditions, the interaction of ISI and stimulus intensity reached a significant level $F(2{,}50) = 14.67$, $p = <.0001^{**}$ as well as for the interaction of ISI and brain hemisphere $F(2{,}50) = 10.61$, $p = <.0001^{**}$.

The post-hoc ANOVA (1000 ms, 2000 ms, 4000 ms)did not yield a statistically significant effect for the triple interaction of ISI, brain hemisphere, and intensity modulation ($F(2{,}50) = 0.67$, $p = 0.5140$).

Table 4.4.: Statistical Analysis N1m – Interstimulus Interval

Source	df	F-Value	p-Value
ISI*Intensity	2, 50	14.67	<.0001**
ISI*Hemi	2, 50	10.61	<.0001**
ISI*Hemi*Intensity	2, 50	0.67	0.5140

Note. * p-Wert < .05, ** p-Wert < .01; ISI = Interstimulus Intervals, Intensity = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

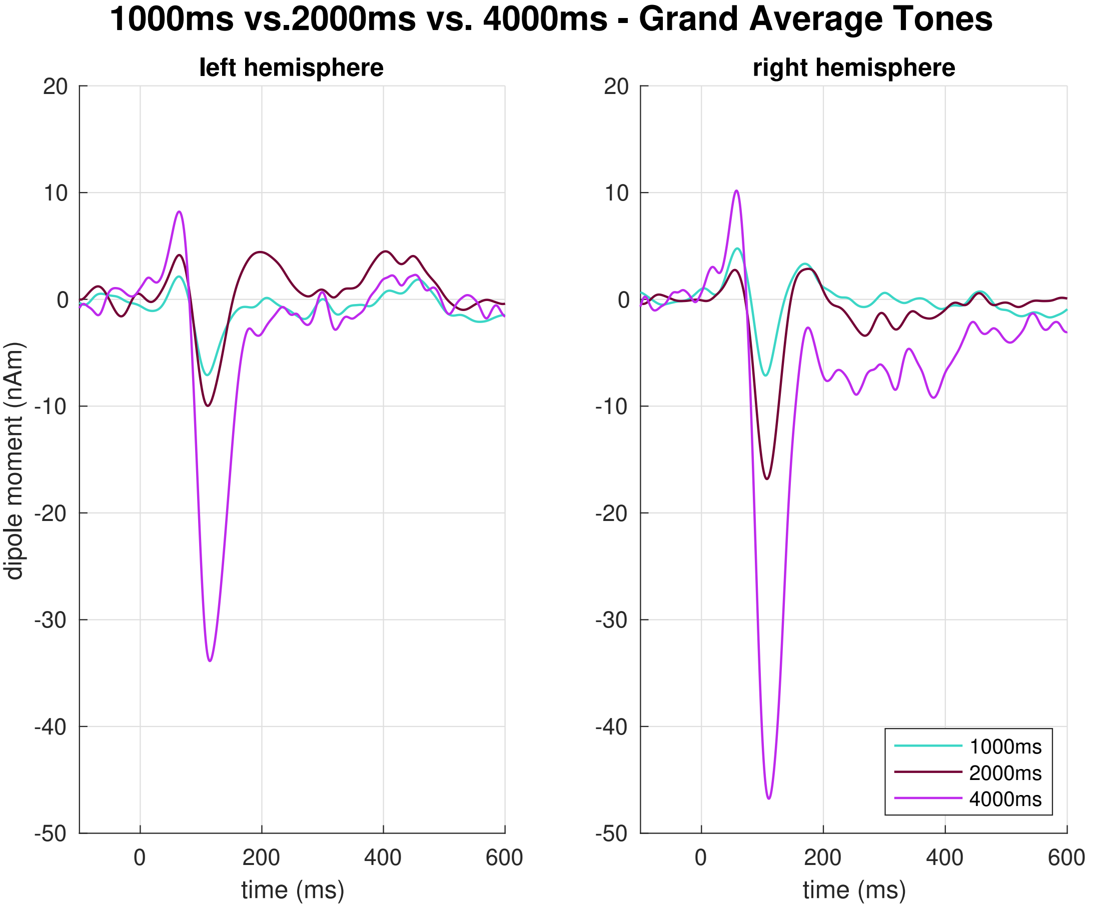

Figure 4.3.: Shown in the columns are the left and right hemispheres. The groups are pooled across intensity-modulated conditions but separated by the three ISI conditions.

The 4000 ms ISI condition gives rise to a much higher peak in both hemispheres compared to 2000 ms and 1000 ms conditions (see figure 4.3). For the hemisphere effect, the contralateral side of the stimulated ear shows a higher peak for the

2000 ms and 4000 ms conditions. This finding is in line with hypothesis H1-2, where it was postulated that the amplitude of the N1m would increase with increasing the interstimulus interval.

The grand average of the intensity-modulated tones comparing all three conditions shows that the low- and high-intensity-modulated tone averages increase in amplitude with increasing ISIs for both groups (high vs. low grand average tones; see figure 4.4). The increase of the amplitude of the N1m component also shows a smaller peak for low than for the high-intensity-modulated tone stimuli in all conditions. This is descriptively in line with Hypothesis H1-2. It should also be noted that for the 1000 ms condition, the mean low-intensity group shows no noticeable N1m peak. For the 2000 ms and 4000 ms conditions, a clear peak, and an apparent increase can be identified as expected.

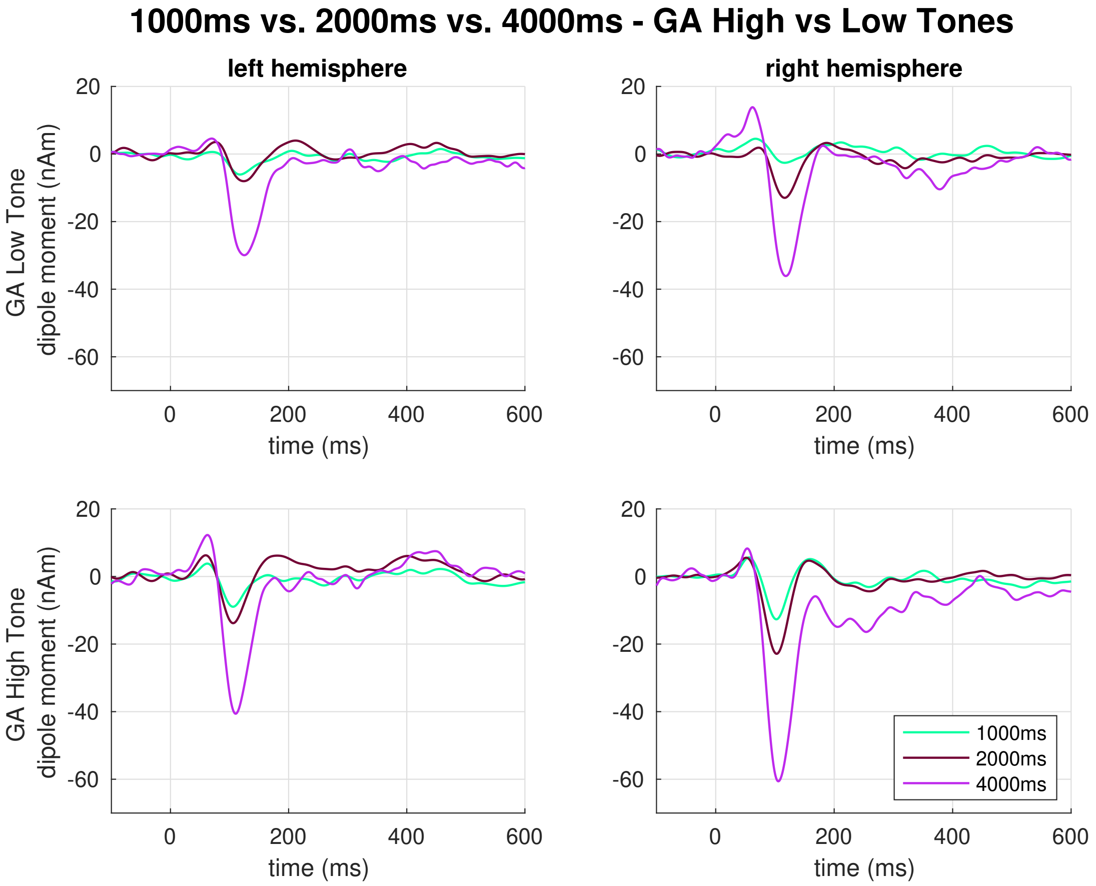

Figure 4.4.: Grand averaged data in response to *low- & high*-intensity-modulated tones in the left and right hemispheres (left & right columns) for each ISI condition.

4.3. N1m & Dynamic range adaption

4.3.1. H2-1 – DRA & Amplitude Modulation

For examining the dynamic range effect on the N1m amplitude, figure 4.5 shows the result of the grand average of the N1m of all ISI conditions combined. An average was computed for each tone considering the presentation sequence (first tone: t1/t5, second tone: t2/t6, third tone: t3/7) to enhance the signal-to-noise ratio for the comparison of the dynamic range adaption. The statistical analysis for the H2-1 hypothesis did yield a significant effect for the dynamic range adaption of the N1m component studied $F(2{,}50) = 5.88$, $p = .0.0051^{**}$, but the interaction between DRA and intensity modulation did not prove to be significant. The same applies to the brain hemispheres and the interaction of all three. Table 4.5 lists the outcomes for the interaction effects for the dynamic range adaption and stimulus intensity as well as the hemisphere, which did not reach a significant level. Thus hypothesis H2-1 can not be confirmed.

Table 4.5.: Statistical Analysis N1m & DRA – Amplitude Modulation

Source	df	F-Value	p-Value
DRA	$2, 50$	5.88	0.0051^{**}
DRA*Intensity	$2, 50$	2.84	0.0680
DRA*Hemi	$2, 50$	2.21	0.1205
DRA*Intensity*Hemi	$2, 50$	1.80	0.1756

Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$; DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity-modulated stimuli, Hemi = Hemisphere

In figure 4.5 the N1m component shows a slightly higher amplitude for the first tone presentation in the contralateral hemisphere and decreases for the third tone (t3/t7). It can only be observed in the right hemisphere. This is in line with H2-1 hypothesis, but since the measured difference is very small and not statistically significant, it has to be assumed, that this effect can not be confirmed. The comparison of each individual stimulus of the intensity-modulated tone train averaged over all conditions shows a very minor difference in the high-intensity-modulated tones group for the contralateral side of stimulation

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Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$

(see figure 4.6). Here the first tone (t5) showed an N1m amplitude with a slight amplitude reduction for the consecutive stimuli presentation (t6, t7). Even so, this descriptive trend would be in line with the H2-1 hypothesis, which postulated a decrease from the first to the second tone of each train for the high-intensity-modulated tone train, this difference is marginal and statistically not significant. Therefore the hypothesis can not be confirmed. It should be noted that in the low-intensity-modulated tone averages for either hemisphere, this can not be found. In contrast, the low-amplitude modulated tones show the most prominent peak for the second tone (t2) in the tone train. This was not expected in the hypothesis and thus contradicted the postulate that the first tone (t1) should elicit the highest amplitude.

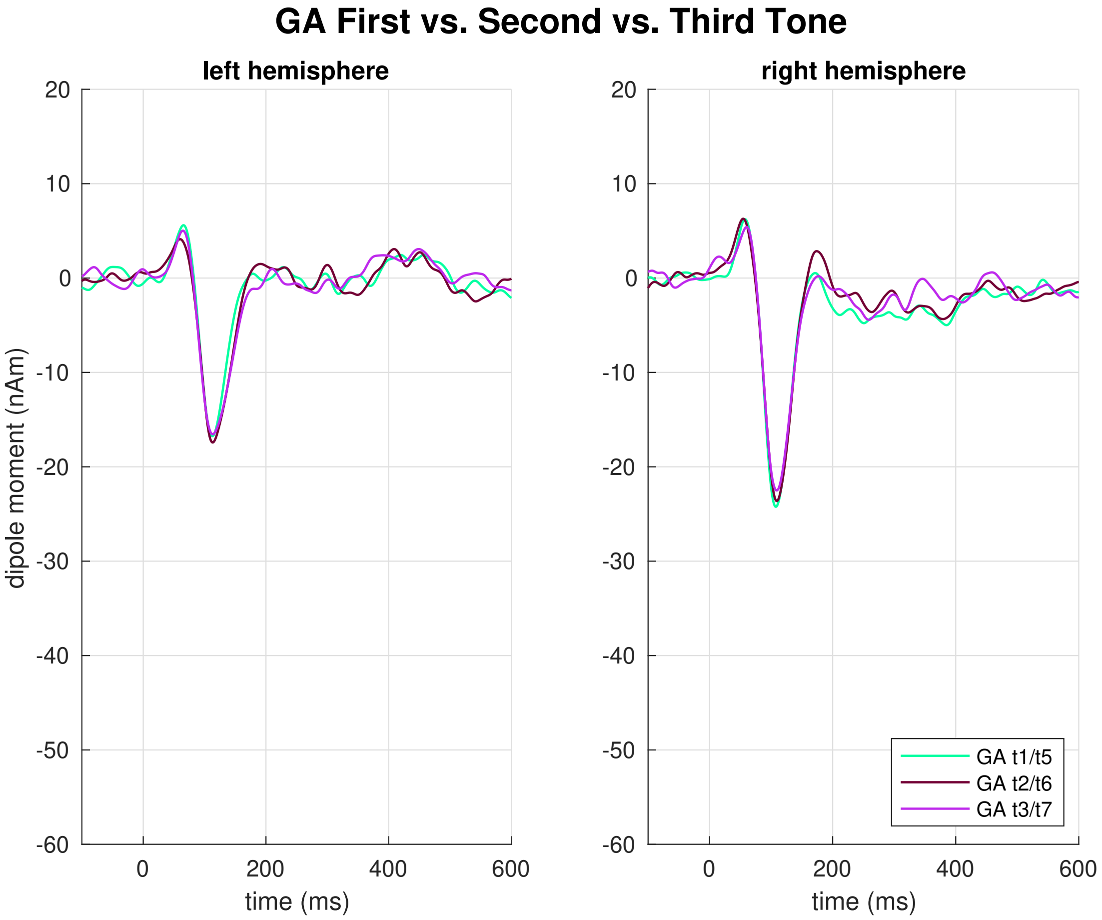

Figure 4.5.: This figure shows the grand average of the first (t1 & t5) vs. second (t2 & t6) & third (t3 & t7) tone stimuli of each sequence (High/Low).

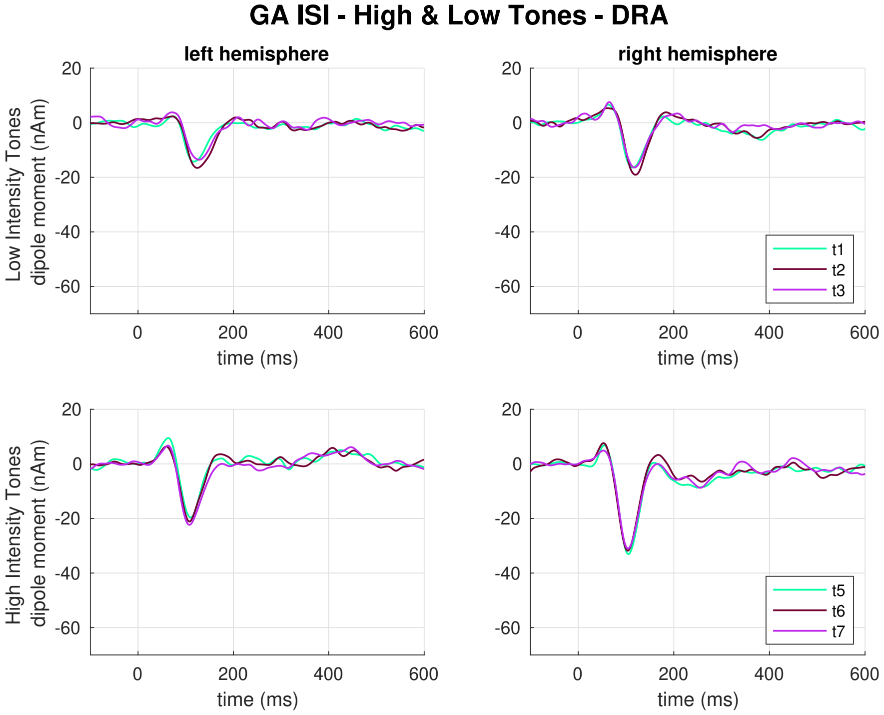

Figure 4.6.: Grand average of the ISI conditions for each of the tone stimuli of the intensity-modulated tone trains. For the high-intensity-modulated tone group, a decrease of the N1m component can be seen in the contralateral side with each consecutively presented tone stimulus.

4.3.2. H2-2 – DRA & Interstimulus Interval

For examining the influence of the Interstimulus Interval and the dynamic range adaption for all three ISI conditions figure 4.7 shows the data for low-intensity modulated tones and figure 4.8 for high-intensity modulated tones. The statistical analysis for the H2-2 hypothesis did not yield a significant effect (Table 4.6).

Table 4.6.: Statistical Analysis N1m & DRA – Interstimulus Interval

Source	df	F-Value	p-Value
DRA*ISI	4, 100	2.43	0.0524
DRA*ISI*Intensity	4, 100	0.53	0.7170
DRA*ISI*Hemi	4, 100	1.40	0.2399
DRA*ISI*Intensity*Hemi	4, 100	0.61	0.6569

Note. * p-Wert $< .05$, ** p-Wert $< .01$;
ISI = Interstimulus Intervals, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Group = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

Figure 4.7 and figure 4.8 both show an increase in the N1m with higher ISI but a very small or no deviation between the individual tones (t1, t2, t3 and t5, t6, t7) for every ISI. The amplitude for the higher ISI is bigger than the amplitude for the lower ISI. Figure 4.7 shows the low-intensity-modulated tone trains for all three ISI conditions. In the 1000 ms condition, no observable peak can be noticed for the N1m component for all stimuli presented, whereas the 2000 ms and 4000 ms conditions show an identifiable peak. In these conditions, the first presented tone (t1) does not show an enhanced peak compared to the following stimuli (t2, t3). It should also be noticed that the first tone (t1) shows the smallest peak in the right hemisphere and no noticeable difference in the left hemisphere of all three tones presented in the 4000 ms condition. In the evaluation of the high-intensity-modulated tone group in figure 4.8, a peak of the N1m can be identified for each ISI condition. In this group, a more substantial amplitude can also be observed in the right hemisphere (ipsilateral to stimulation). For the dynamic range adaption, the 1000 ms condition shows a slightly higher amplitude for the t5 compared to the consecutive t6 and t7, where this effect is more apparent on the contralateral side. In the left hemisphere (ipsilateral to stimulation), both the 2000 ms and 4000 ms conditions do not show an increased N1m for the first stimulus. Merely the 2000 ms condition shows a minor difference between the first (t5) to the second and third stimulus (t6, t7), which is most apparent in the right hemisphere. The 4000 ms condition does not show any effects between the three-tone presentation. This is partly in line with hypothesis 2-2, which stated that a decrease between the first and consecutive tones was expected in the 1000 ms condition. This was observable in the evaluation of the high-tone stimuli. It was not expected to see this effect in the 2000 ms condition, but here it should be noted that the effect is minor in this condition. Hypotheses 2-2 postulated that there would be a decline from first to consecutive tones in the 1000 ms conditions, which is not supported by the data. It also postulates that the decline of the N1m amplitude would be observable for low and high-intensity modulated tones. Thus the results do not support the H 2-2.

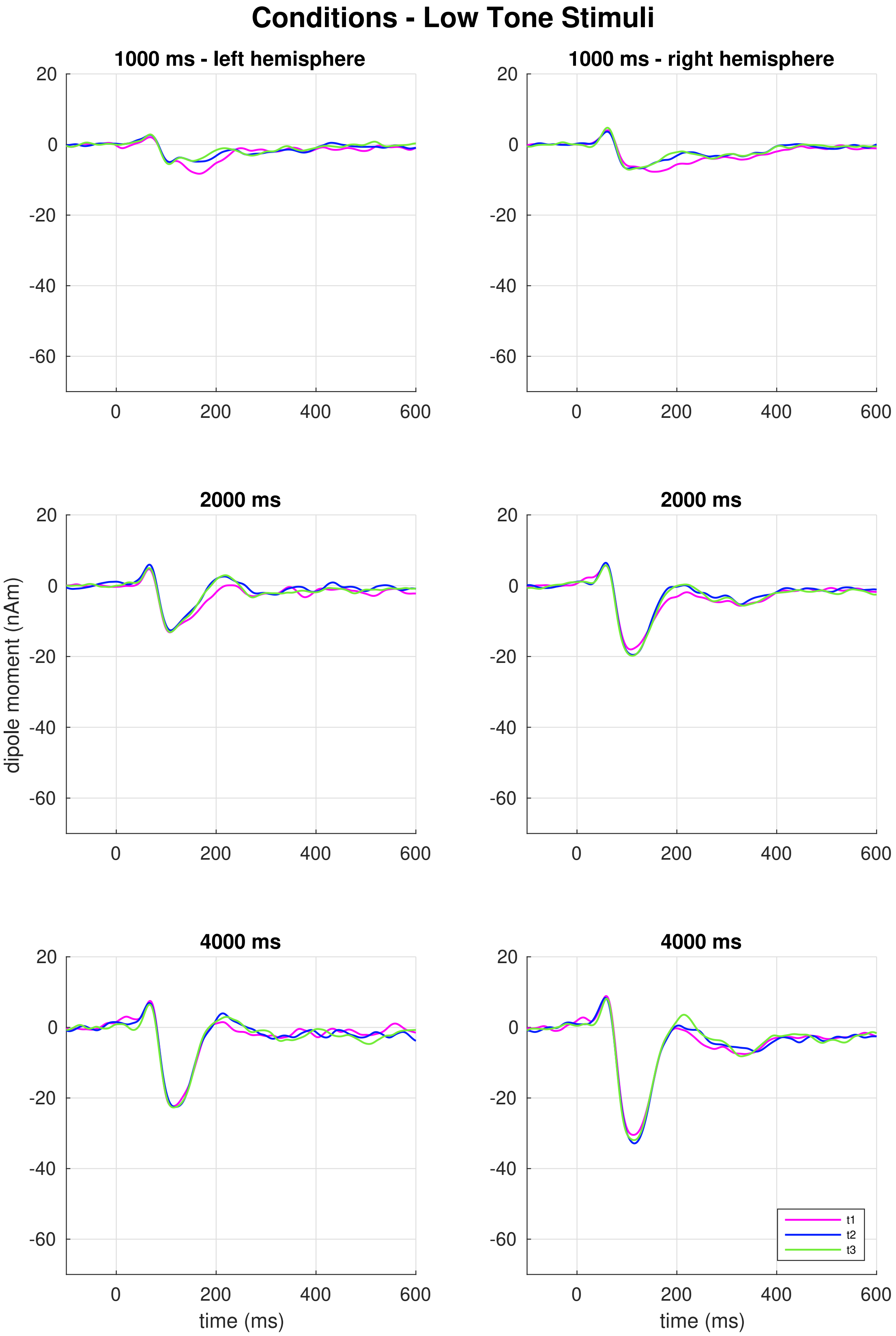

Figure 4.7.: This figure shows each condition (1000 ms, 2000 ms and 4000 ms) for the individual tone stimuli in the low tone group (t1, t2, t3).

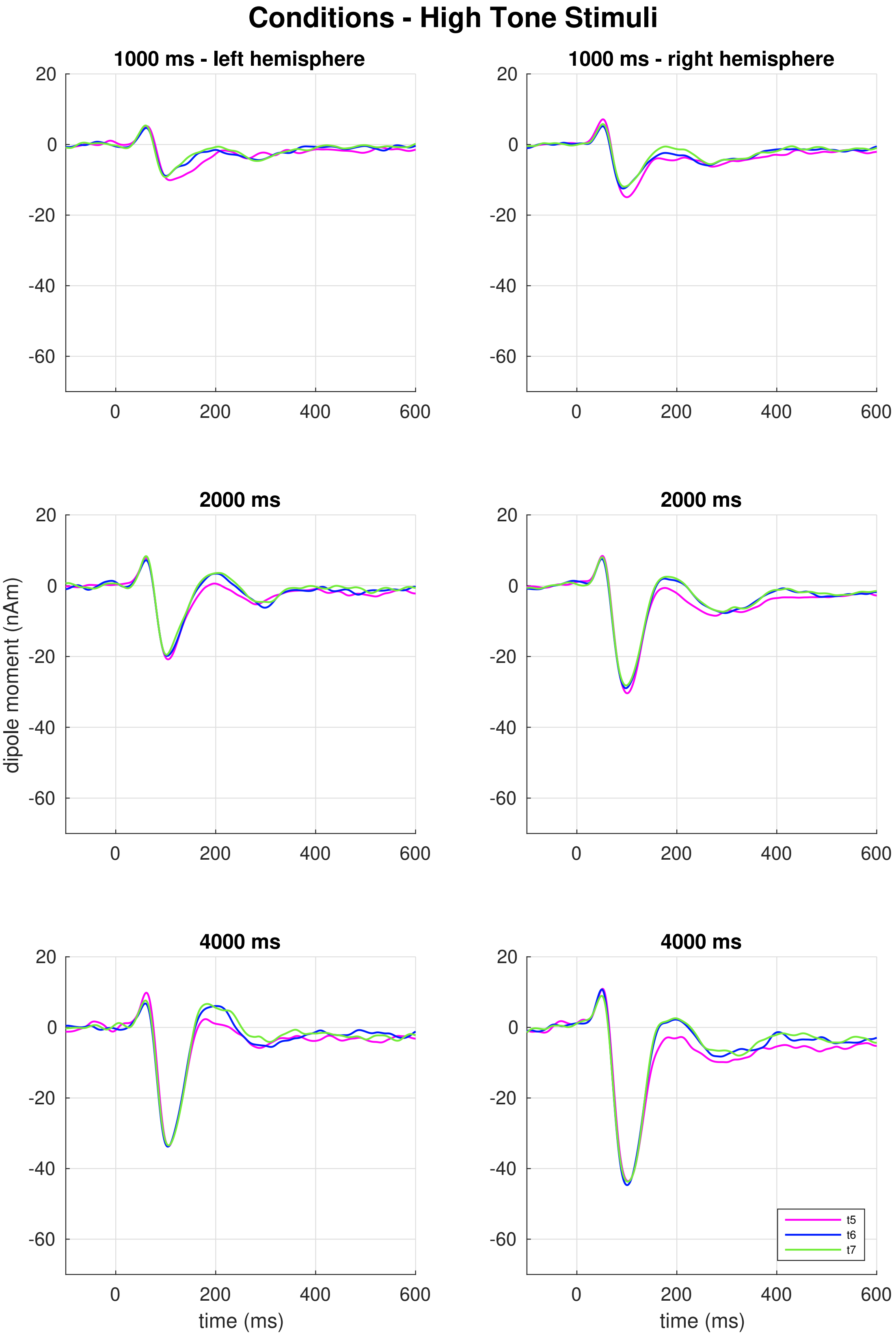

Figure 4.8.: This figure shows each condition (1000 ms, 2000 ms and 4000 ms) for the individual tone stimuli in the high tone group (t5, t6, t7).

4.4. N1m & Musicality

4.4.1. H3-1 – Musicality & Amplitude Modulation

The aim of the third question was to study whether the level of musicality of the participants affects the N1m component. The datasets were averaged across all ISI conditions to enhance the signal-to-noise ratio. The waveforms were statistically tested for effects of AMMA, stimulus intensity, brain hemisphere, and the triple interaction of all three. The repeated measures ANOVA did not show any significant effect on any of the tested variables. Table 4.7 shows the results of the statical testing.

Table 4.7.: Statistical Analysis Musicality – Amplitude Modulation

Source	df	F-Value	p-Value
AMMA	$1, 25$	0.02	0.8994
AMMA*Intensity	$1, 25$	1.22	0.2802
AMMA*Hemi	$1, 25$	0.99	0.3299
AMMA*Intensity*Hemi	$1, 25$	0.04	0.8521

Note. * p-Wert $< .05$, ** p-Wert $< .01$; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

The results in figure 4.9 show a difference between AMMA high and AMMA low in the low-intensity-modulated tone trains between both hemispheres. On the ipsilateral side, the AMMA low group elicits the higher peak, whereas, on the contralateral side, the AMMA high group elicits the highest amplitude. The high-amplitude tone trains evoke a high peak for the AMMA high group in both hemispheres, where the difference is more prominent in the left hemisphere. A minor enhancement of the peak for the AMMA high group can be noticed for the high-intensity-modulated tone trains in the right hemisphere. The postulated difference between the *AMMA high* and *AMMA low* group is observable for all intensity-modulated tone groups, but the effects differ in strength and hemisphere distribution. Thus, the high-intensity-modulated tone groups and the right hemisphere of the low-intensity-modulated tone group are visually in line with hypothesis H3-1. However, since none of the calculated results reach statistically significant levels, the H1 has to be rejected.

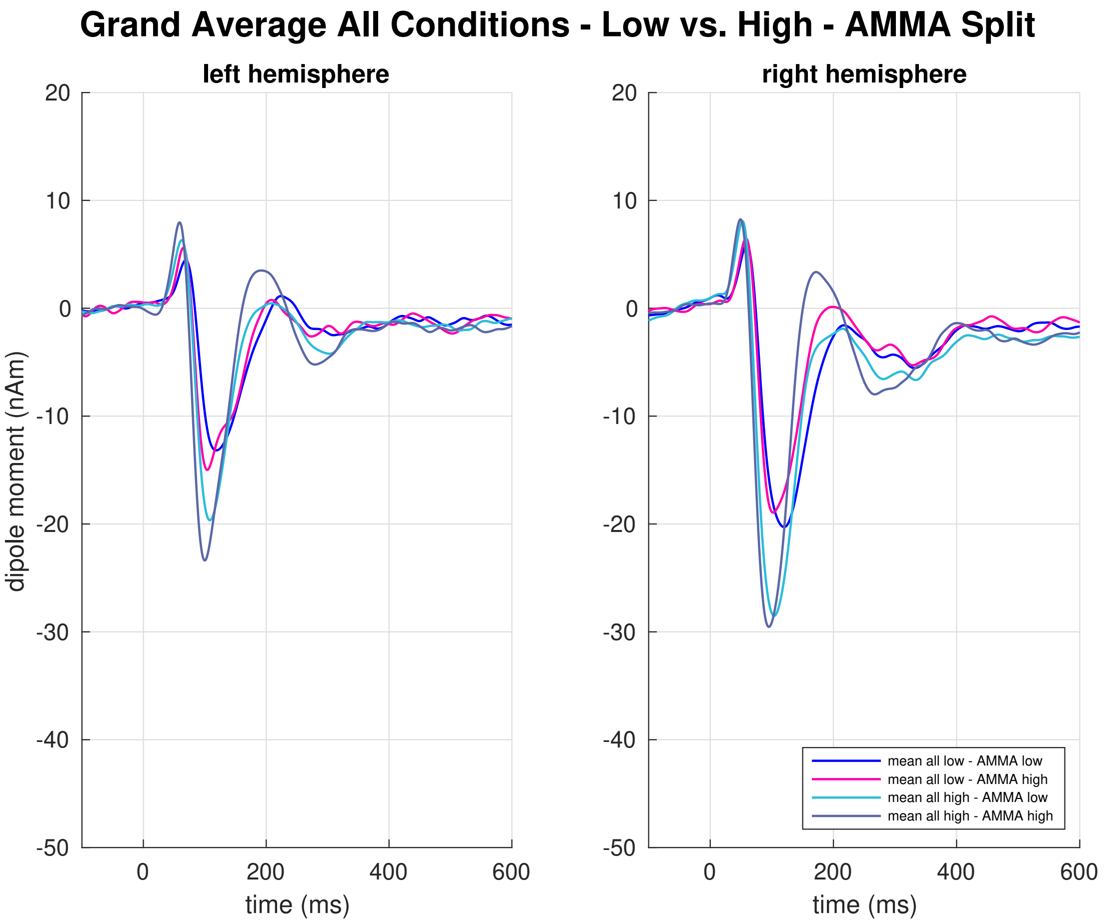

Figure 4.9.: The grand average over all conditions (1000 ms, 2000 ms and 4000 ms) grouped by high- and low-intensity-modulated tones (high vs. low intensity of tones) and *AMMA high* and *AMMA low* results.

4.4.2. H3-2 – Musicality & Interstimulus Interval

To examine the effects of musicality for the individual ISI conditions, the grand averages over all intensity-modulated tone trains for each ISI and AMMA group were calculated (Figure 4.10). Table 4.8 shows the outcomes of the repeated measures ANOVA for the research question of effects of the ISI and musicality, which were examined for hypothesis H3-2. Neither the AMMA scores (musicality) and ISI conditions nor the studied interaction effects reached the level of significance. Thus no trends of the studied N1m component observed in the waveforms could be confirmed as statistically significant. The H1 of the H3-2 has to be rejected.

Table 4.8.: Statistical Analysis Musicality – Interstimulus Interval

Source	DF	F-Value	p-Value
AMMA*ISI	2, 50	0.57	0.5698
AMMA*ISI*Intensity	2, 50	1.58	0.2155
AMMA*ISI*Hemi	2, 50	0.73	0.4873
AMMA*ISI*Intensity*Hemi	2, 50	0.45	0.6398

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

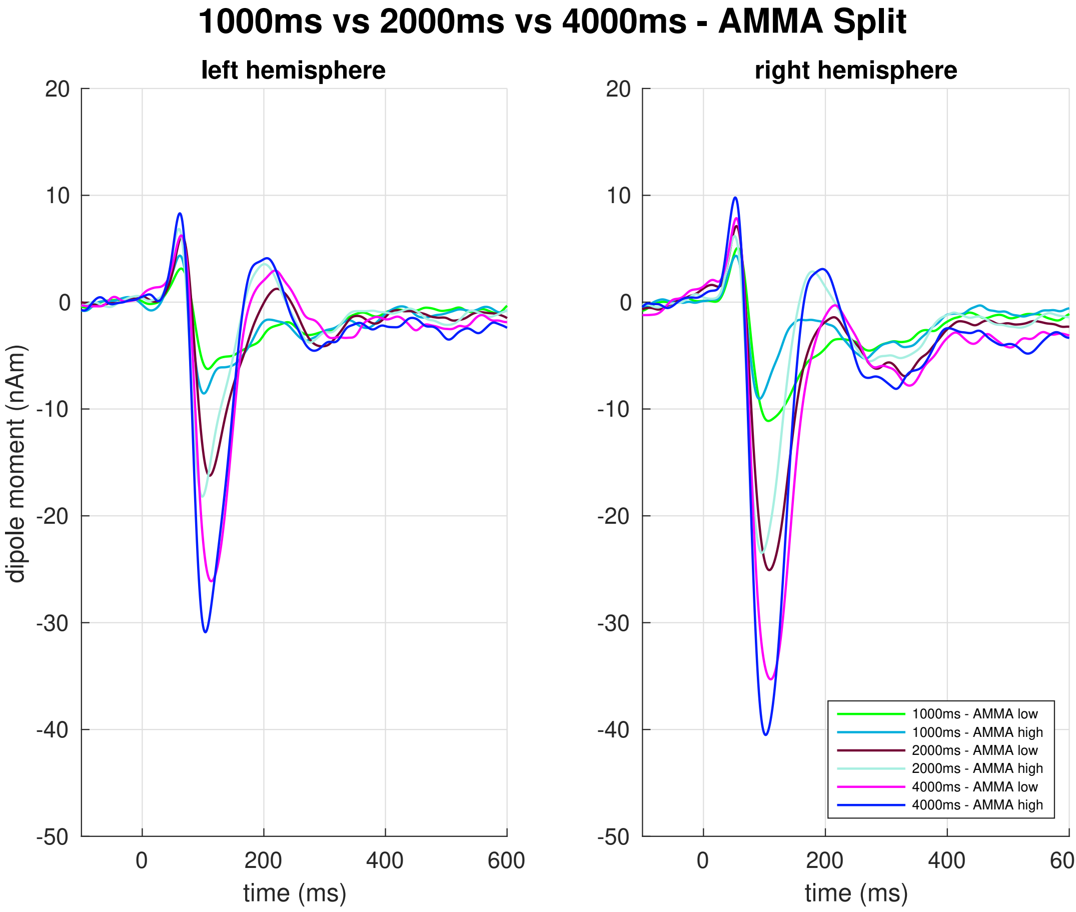

Figure 4.10.: Data of left (ipsilateral to stimulation) and right hemisphere (contralateral to stimulation). The data shown are averages across all intensity-modulated tones within the 1000 ms condition, 2000 ms condition, and the 4000 ms condition. These groups are also separated for into the AMMA groups *AMMA high* vs. *AMMA low* values.

The data in figure 4.10 show a peak for all three ISI conditions on both hemispheres. The *AMMA high* group displays a bigger N1m amplitude at 4000 ms ISI in the right hemisphere and at all ISI in the left hemisphere. This finding would support the hypothesis. However, at 1000 ms and 2000 ms in the right hemisphere the *AMMA low* participants are measured with higher N1m amplitude compared to the *AMMA high* participants, which contradicts the hypothesis, while in the left hemisphere *AMMA high* has bigger amplitudes. To get a more detailed look, figure 4.11 shows the grand average of the high- and low-intensity modulated stimuli groups for the specific ISI as well as the AMMA groups. Overall, the peaks show a more prominent amplitude on the contralateral side. In the 1000 ms ISI condition, the low intensity-modulated tone group shows no clear N1m peak for both AMMA groups. The expected higher N1m amplitude for the *AMMA high* group can only be observed in both hemispheres at 4000 ms ISI and high amplitude tones. The difference between *AMMA high* and *AMMA low data* data of the low-intensity-modulated tone group at 4000 ms ISI is much smaller in both hemispheres. At the 2000 ms ISI the effect flips between *AMMA high* and *AMMA low data*, the difference is marginal for both intensity groups. The expected effect can therefore only be observed in the measured data at 4000 ms ISI but does not reach statistical significance. H3-2 has to be rejected.

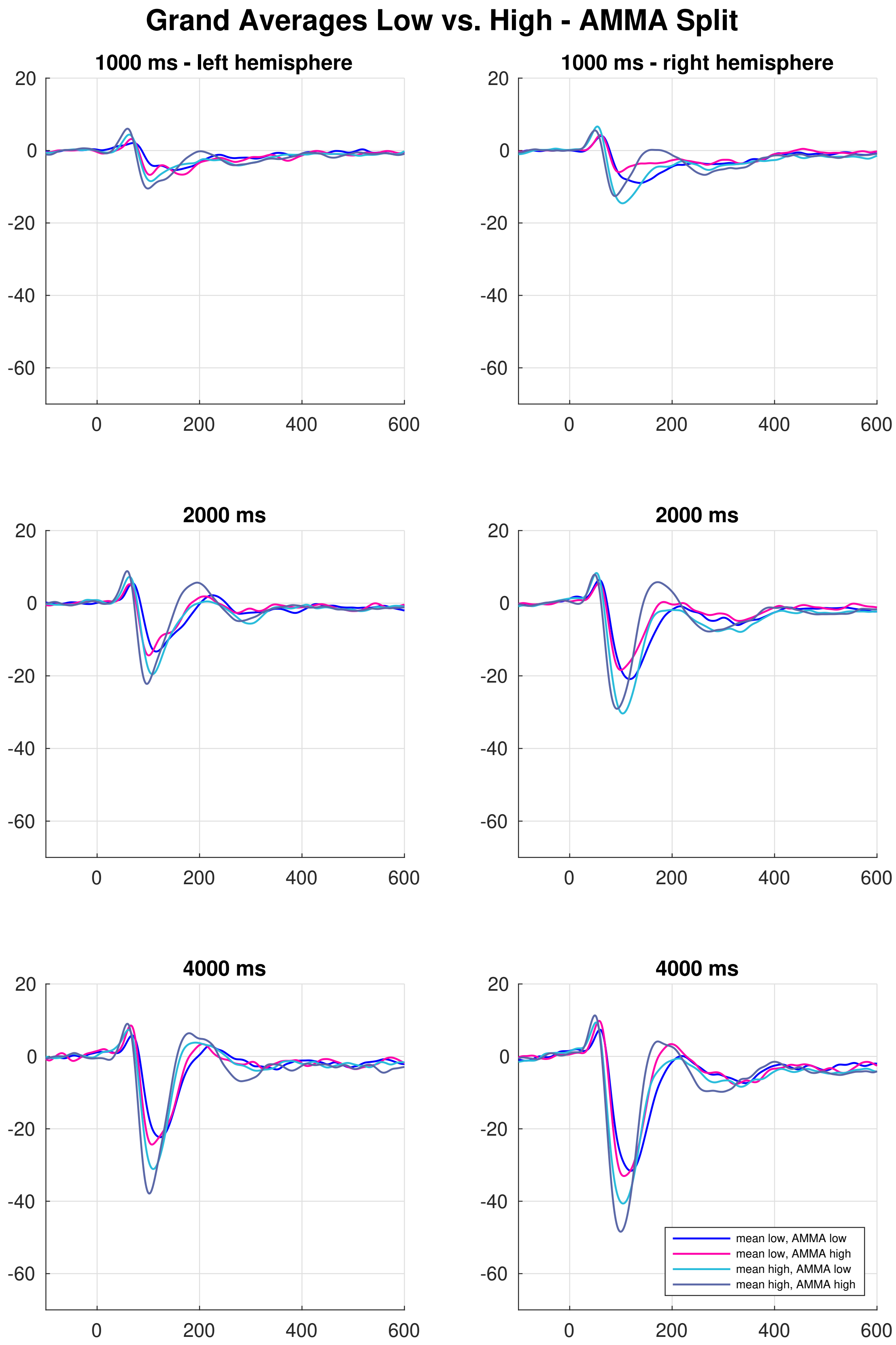

Figure 4.11.: Grand averaged data of tone points *low vs. high amplitude tones* in the left and right hemispheres (left & right columns) as well as the three conditions of ISI in the rows (1000 ms, 2000 ms, 4000 ms). These groups are split into two groups with regard to the AMMA scores.

4.5. N1m & Dynamic range adaption & AMMA scores

4.5.1. H4-1 – DRA & Amplitude Modulation & AMMA Scores

The final research question was to investigate the effects of musicality regarding the dynamic range adaption and ISI condition on the amplitudes of the N1m. In H4-1 the difference between the first and the following tones of the sequences was investigated. In figure 4.12 the grand average over all ISI conditions was separated into the *low AMMA* group (upper row) and *high AMMA* group (lower row), each displaying the high intensity-modulated tones (t1, t2, t3) and low intensity-modulated tones (t5, t6, t7). The statistical testing for effects of the dynamic range adaption and the interaction with musicality (AMMA group) and intensity of stimuli did not reach statistically significant levels. Further triple and quadruple interaction also showed no significant results. The outcome of the repeated measures ANOVAs for H4-1 are outlined in table 4.9. These findings result in the rejection of H1 for hypothesis H4-1.

Table 4.9.: Statistical Analysis Musicality & DRA – Amplitude Modulation

Source	df	F-Value	p-Value
DRA*AMMA	2, 50	0.10	0.9053
DRA*Intensity*AMMA	2, 50	0.06	0.9383
DRA*Hemi*AMMA	2, 50	1.65	0.2024
DRA*Intensity*Hemi*AMMA	2, 50	1.00	0.3760

Note. * p-Wert < .05, ** p-Wert < .01; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity stimuli, Hemi = Hemisphere

For the *low AMMA* group, no difference can be observed between the different tones, except a minor increase of the t5 compared to the t6 and t7 stimuli in the high intensity-modulated tone group in the right hemisphere. This cannot be seen for the *low AMMA* group in the low intensity-modulated tone group (t1, t2, t3). For the *high AMMA* group (bottom row), neither of the intensity-modulated tone groups showed a noteworthy difference in amplitude for the tone sequences in both hemispheres. Only the already observed increase of the amplitude for the high-intensity-modulated tones compared to the low-intensity-modulated tones is evident. Overall, these findings contradict the H4-1, where a difference between the AMMA groups was postulated.

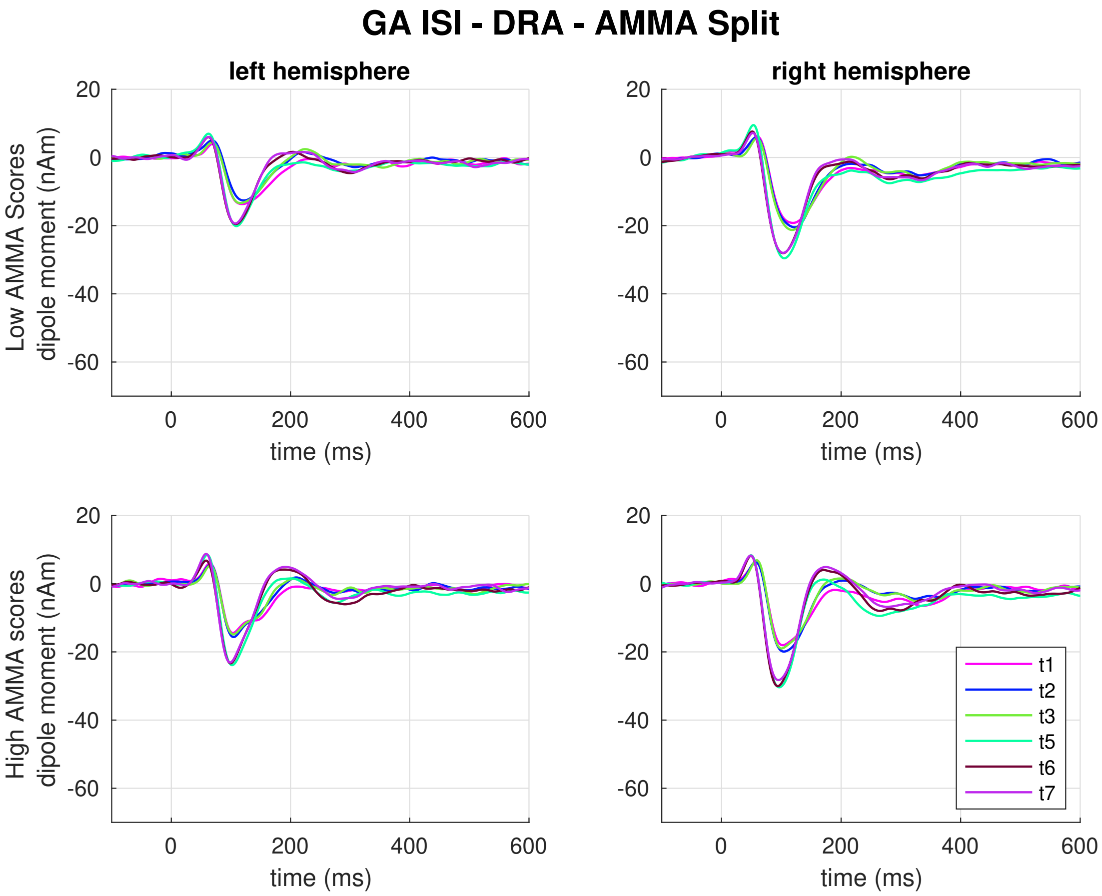

Figure 4.12.: In figure 4.12 the grand average over all ISI conditions was separated into the *low AMMA* group (upper row) and *high AMMA* (lower row) each depicting the data of the high intensity-modulated (t1, t2, t3) and low intensity-modulated (t5, t6, t7) tones. Neither the *low AMMA* nor the *high AMMA* shows a clear difference in the evoked amplitude in the sequence of tones.

4.5.2. H4-2 – DRA & Interstimulus Interval & AMMA scores

This research question investigated interactions of dynamic range adaption, as well as the effects on the brain hemisphere focusing on the ISI condition and musicality. The repeated measure ANOVA did not find statistically significant interactions between the studied variables. For the results, see table 4.10. None of the expected waveform effects did reach significance. For hypothesis H4-2, the H1 has to be rejected.

Table 4.10.: Statistical Analysis Musicality & DRA – Interstimulus Interval

Source	df	F-Value	p-Value
DRA*AMMA*ISI	4, 100	0.27	0.8994
DRA*ISI*Intensity*AMMA	4, 100	0.82	0.5147
DRA*ISI*Hemi*AMMA	4, 100	1.57	0.1800
DRA*ISI*Intensity*Hemi*AMMA	4, 100	1.30	0.2748

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

To examine the DRA effect in the low-intensity-modulated tone sequence, the following graphics show the different ISI conditions, AMMA groups, and the waveforms elicited by the individual tones divided into the low and high-intensity-modulated tone groups. Figure 4.13 shows the results of the low-intensity-modulated tones. The 1000 ms condition yields no clear peaks or differences of the N1m component for the particular stimuli for either of the AMMA groups. The 2000 ms condition contralateral shows an increase of amplitude for the *low AMMA* group, while ipsilateral *high AMMA* group has a marginally higher tendency. The 4000 ms condition both hemispheres display a slide increase for the *high AMMA* group.

For the high-intensity-modulated tone group results are shown in figure 4.14. In the 1000 ms condition, ipsilateral, the N1m amplitudes for the *low AMMA* group do not show a clear peak. Contralateral, the condition yielded more precise peaks. For the *low AMMA* shows the highest amplitude for t5, followed by a decrease of t6 and t7 with an equal height. Regarding the *high AMMA* group, a slight decrease from t5 to t6 and t7 is observable. In the 2000 ms condition, no peak differences can be noted for the *low AMMA* in the left hemisphere. In the right hemisphere, this group showed the highest amplitude for t5, decreasing t6 and t7 (which evoked the same amplitude height). The *high AMMA* group showed the biggest amplitude for t5, followed by t6 and t7 (equal height) on the ipsilateral side. The contralateral side showed a continuous amplitude decrease from t5 to t6 to t7. There is no observable amplitude difference in the left hemisphere for the 4000 ms condition within the *low AMMA* and the *high AMMA* group. The amplitude of the *high AMMA* group is bigger compared to the *low AMMA* group. The same effect can be seen in the right hemisphere with a minor difference for the *high AMMA* group, where t6 evoked a slightly large amplitude than t5 and t6. The results of comparing the ISI of the different *AMMA* groups show a shift between low and high *AMMA* scores which differs from within the ISI conditions. The effect of an increasing amplitude between ISI conditions (higher amplitude with increasing ISI) can be seen only partially. The amount is only clearly visible in the 4000 ms interval. There is no significant increase of N1m amplitude considering the *group AMMA* for each individual ISI interval. This is not in line with H4-2.

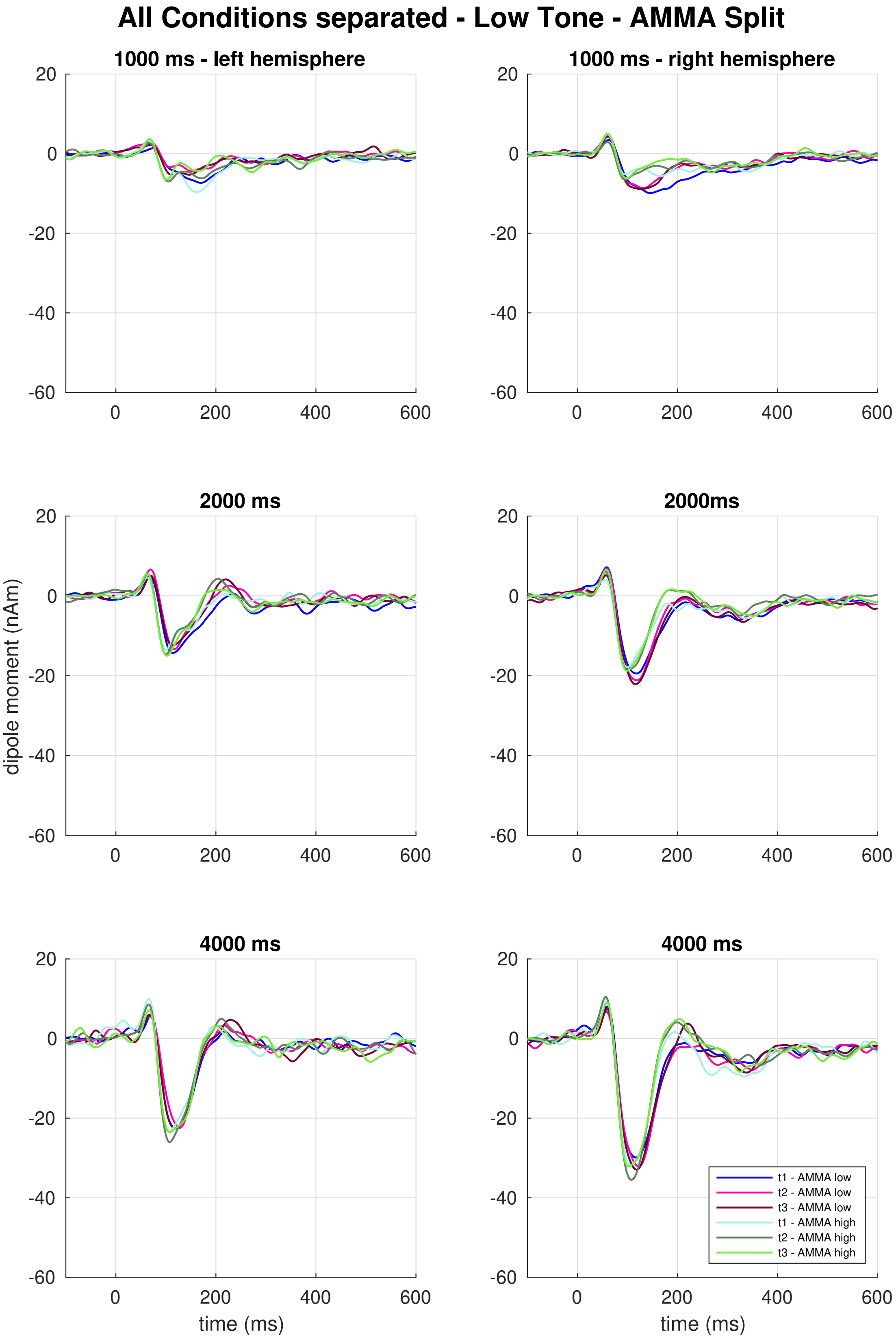

Figure 4.13.: Shown in these columns are the responses to the left (ipsilateral) and right hemisphere (contralateral). Displayed are the individual stimuli for the low-intensity-modulated tones, which are also divided into the AMMA groups *AMMA high* vs. *AMMA low*.

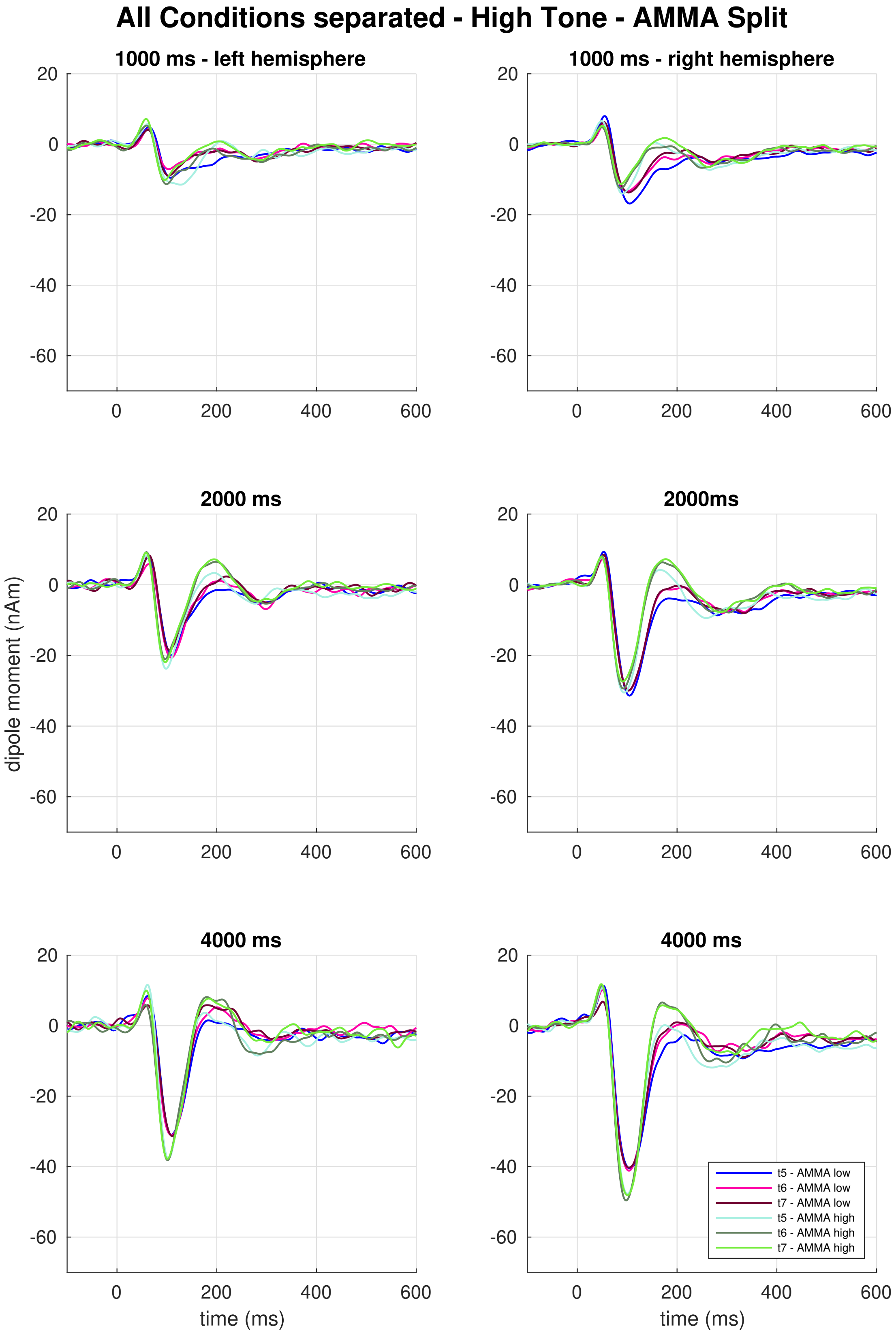

Figure 4.14.: Shown in these columns are the responses to the left (ipsilateral) and right hemisphere (contralateral). The individual stimuli in this graphic are plotted for the high-intensity-modulated tons, which are also divided into the AMMA groups *AMMA high* vs. *AMMA low*.

5. Discussion

The aim of the present study was to analyze aspects of the auditory N1m component in relation to variables such as interstimulus intervals, dynamic range adaptation, and musicality. It is known that the N1m is an auditory transient component that is sensitive to different interstimulus intervals, so the first part of the evaluation focused on these aspects. The further examination intended to investigate the effect on the N1m as a measure of musicality and the implication for the dynamic range adaption effects. To explore these effects, four main hypotheses were investigated, which focused on the amplitude variation and the interstimulus intervals for each of the four studied factors (N1m component effects of stimulus intensity, dynamic range adaption of N1m, musicality effects on N1m and musicality effects of N1m in respect to dynamic range adaption). The next paragraphs follow this structure by discussing the main findings and placing them in the current literature.

5.1. N1m, ISI & intensity effects

At the beginning, it was important to replicate the known effects of different ISI lengths to ensure that the placed dipoles reflected the auditory N1m component at the expected locations in the AC to validate the study design. The expected position of the N1m was the planum temporale (e.g. Loveless et al., 1996; Lütkenhöner & Steinsträter, 1998; Sams et al., 1993). The main finding regarding the ISI effects is in line with the results for short ISIs from Lu et al. (1992), who showed a strong response of a single dipole in the contralateral hemisphere of stimulation. The investigation of the first question of the present study confirms, that the contralateral side of stimulation shows a more pronounced N1m peak in almost all evaluations conducted. The effect of the interstimulus interval as a property of the stimulus presentation has been widely studied and is known to be a stable effect. This important ISI effect was studied by Hari et al. (1987), who demonstrated that an increase in ISI leads to an enhancement of the amplitude of the N1 component.

This effect was replicated several times (Budd & Michie, 1994; Loveless et al., 1996; Sable et al., 2003). This pattern is in line with the results of the current study, showing an increase of N1m amplitude from the smallest to the highest ISI, especially in the evaluations which focused on the grand average of the N1m in section 4.2. The present results also showed that the difference between the shorter ISIs (1000 ms & 2000 ms) conditions and the larger ISI (4000 ms) show a greater increase. This supports the earlier findings mentioned above that a higher ISI results in a greater amplitude of the N1m component. Another essential part of this study is the confirmation of the amplitude modulation with respect to the intensity of the stimuli applied. The results of Röhl and Uppenkamp (2012) and Soeta and Nakagawa (2012), who reported stronger BOLD signals, as well as high MEG activation, as the intensity of the stimulus increased in the corresponding processing locations. These neurophysiological findings could also be shown in the present study in the results of section 4.2 showing higher activation, thus a higher amplitude for the high-intensity stimuli. Grand averages were computed to examine this effect thoroughly, showing the known lateralization effect, which was already described above, and the increase of N1m amplitude from low to high-intensity stimuli. This increase was more pronounced for the contralateral side of stimulation. Furthermore, it was essential to investigate the separation of the ISI effects and the augmentation in response to the intensity increase. Here the low and high stimuli fields were divided into three conditions. The findings show an increase of N1m amplitude from low to high stimuli within each ISI condition (see section 4.2.2). These results suggest the N1m amplitude was influenced by the interstimulus interval as well as by the property of the intensity of the stimulus resulting in a different intensity of augmentation for each combination. This is in line with the literature about the intensity and ISI effects of the N1m component (Budd & Michie, 1994; Loveless et al., 1996; Sable et al., 2003). The statistical tests in this study revealed a significant difference in amplitude between the grand average of stimulus tones and the three ISI conditions and a for the grand average of intensity groups (high vs. low) and ISI. The testing of the difference between ISI and brain hemisphere also reached a statistically significant level (see section 4.2.2). These statistical findings are in line with the literature presented above.

As there is no evidence in the literature that varying the frequency of the applied stimulus would show a significant relevant difference in terms of increase in intensity, the fact that only one carrier frequency was used in this study can be considered an advantage (e.g. Harris et al., 2007). The chosen intensity levels have widely been used to study the intensity effect in EEG and MEG studies and thus have been proven to show stable outcomes (e.g. Neukirch et al., 2002; Paiva et al., 2016). Therefore the use of more than one frequency did not seem to reveal any further information or value but rather to be a potential source confound to the intended study outcomes.

5.2. Dynamic range adaption effects

The next research question investigates the dynamic range adaption effects related to the different ISIs and the two intensity modulations applied in the study. The dynamic range adaption effect describes the assumption that the repetition of a stimulus leads to a decrement of the amplitude when tones with identical properties are presented multiple times. To reach a higher signal-to-noise ratio, the first approach to study the DRA effect was based on averaging the response to the first tone of each of the high- and low-intensity tone trains (see section 4.3, figures 4.5 & 4.6). The descriptive results of the measured waveforms show a decrement of the N1m in the contralateral side of stimulation with an observable decrement, especially between the first/second, and third tones on the contralateral side. Examining the adaption between the three stimuli separated in to high- and low-stimulus-intensity groups, a difference between the resulting waveforms can be noticed (see section 4.3, figure 4.6). Aside from the hemispheric difference, the stronger activation in the right cortex shows the expected decrement only in the high-intensity group for the first tone compared to the second and third stimulus, which show the same amplitude. It should be noted that this effect does not reach statistically significant levels. The descriptively observed tendency could indicate a still ongoing adaption effect for higher-intensity-stimuli, which could contradict findings of Sable et al. (2004) and McEvoy et al. (1997), which reported a finished inhibitory process by up to 450 ms after the onset of each tone. The above results show this effect at 1000 ms for high-intensity stimulation, while at 2000 ms the effect diminishes, and at 4000 ms it does not show at all.

In this context, the differential visual inspection of the potential effect of the varying ISI condition on the dynamic range adaption showed mixed results. The low-intensity stimulus findings do not show stable decrements for the individual tones in any of the three conditions. This could support the assumption that a possible adaption or habituation effect could already be completed by the length of the chosen ISI in the present study. This finding would be expected from all the different explanation approaches above-mentioned. The data, therefore, suggest, that at low-intensity stimuli the dynamic range adaption effect finishes at a shorter time period compared to high-intensity stimuli (see section 4.3.1, figures 4.7 & 4.8). A possible explanation for this visually observable tendency could be a similar effect to the known pitch-onset or pitch-change response as described by (e.g. Gutschalk et al., 2002; Krumbholz, 2003; S. Ritter et al., 2007). Since this study did not have a varying pitch, the pitch-onset or -change effect can not account for the finding.

5.3. Effects of musicality

Studies of the relationship between the AEPs and AEFs and prior music knowledge have shown that an enlarged N1m as a result of higher expertise can be found in musically skilled individuals (e.g. Andermann et al., 2021; Baumann et al., 2008; Pantev et al., 1998). However, there have also been a few contradicting studies (e.g. Lütkenhöner et al., 2006; Shahin et al., 2005). Therefore, the present study first looked at the grand averages of the two intensity groups for the different musical skill levels (high and low) (see section 4.4) before examining further effects of musicality on ISI or dynamic range effects. The grand averages show visual differences in N1m waveform amplitudes between the *AMMA high* and *AMMA low* groups for both intensity levels of the presented stimulus. This is not a consistent finding and did not reach significant levels (for statistics, see section 4.4.1 and 4.7). The present results might have been confounded through the effects of the different ISI intervals, which were average in this part of the analysis procedure. It could be assumed, that the effects differ for different ISIs, and therefore averaging would not be appropriate.

The examination findings of grand averages, including the two intensities for overall ISI conditions, supported this assumption (see section 4.4.2). Interestingly, in the left hemisphere, an increased amplitude for all three conditions for the

AMMA high group becomes observable, but in the right hemisphere, the results vary. The data were further analyzed to get a better insight by separating the ISI conditions, and the two intensity levels applied. However, this meant knowingly decreasing the signal-to-noise ratio of the data. Remarkably all different ISI yielded different results; this may be attributed to the low signal-to-noise ratio or varying effects regarding energy or ISI effects. This was also found in the corresponding statics, which did not reach significant levels (see section 4.4.2, table 4.8). Gutschalk et al. (2002) found a spatial separation for sound processing, especially intensity-specific parts (planum temporale) and auditory regularity (lateral part of the Heschl's gyrus) in their study. Since, in the present study, only one dipole was placed in each hemisphere, and the stimuli were intensity-modulated, but also regular tone trains, the data may have picked up signals from both regions. Despite these factors, a noteworthy observable finding of the measured waveform shows in the results of the 4000 ms condition in figure 4.11. Both intensity-modulated groups show an enhanced peak for the *AMMA high* in contrast to the *AMMA low* group, and for the intensity differences, the enhancement of the increase shows to be greater for the high-intensity-modulated group. This finding points towards the results of an increased N1m for musically skilled individuals, as was reported by Andermann et al. (2021), Baumann et al. (2008), and Pantev et al. (1998). It may also suggest a difference between the intensity-modulated response for differently skilled musical listeners. In comparison, the other ISI conditions showed differences in switching between AMMA groups regarding hemisphere and ISI. This could point towards ISI or intensity effects that differ for different musicality levels. All the visually noticeable differences in amplitude height did not reach statistically significant levels. This leads to the conclusion that musicality does not have a measurable impact on the PT N1m component for the musicality levels investigated in this study.

5.4. Effects of musicality and dynamic range adaption

One of the major aims of this study was to not only look at the intensity effects and musicality in general but to look at the adaption effects of the repetition of tones for these effects. The interaction of musical skills on repetition effects has not been studied until now (to the current knowledge of the author). The examination of the present study results of grand averages computed over the ISI conditions show no adaption effect within the two intensity-modulated tone repetition groups for neither of the AMMA groups (see section 4.5, figure 4.12). Hence it can be concluded that musicality does not seem to play a role in dynamic range adaption effects. Meaning that the results of the review of Sanju and Kumar (2016), which showed the support of overall predominant evidence of enhanced auditory potentials for musicians, could not be found in the present study of the measured PT N1m component. It could be possible that this was the case because the sample of participants did not include professional musicians. Thus based on the literature, it was postulated to see an enhancement of the AEFs for musically skilled participants, the data did not support this assumption on grand average or individual tone level. Thus it did not show any differences in adaption to the stimuli applied between the high and low-musically skilled participants group. This effect was not observable and thus also did not reach statistical significance (for statistics, see section 4.5, table 4.9). The further investigation of the ISI intervals with the separation for the AMMA group and the high- and low-intensity modulated group leads to more varying results than the grand average condition evaluation (see section 4.5, figures 4.13 & 4.14). Although a variety of waveforms can be observed in regard to the different ISI conditions, non of the findings show any tendency nor reach statistically significant levels (see section 4.5, table 4.10). This points towards the assumption that musical skill does not have an effect on the tendency of dynamic range adaption observed in the earlier parts of this study. Since this detailed analysis led to a reduction of the individual data points, there may be an effect that was not visible due to the low signal-to-noise ratio in this evaluation.

6. Conclusion & Outlook

In the studies of auditory potentials, the different relationships between stimulus intensity, interstimulus intervals, dynamic range adaption, and musicality have not been looked at until now. Each of these effects has been studied individually but not in relation to another. The present study aimed to close this gap by replicating the known effects and then extending the evaluation by looking at the connection and interdependencies of these factors. Hereby extending the insights on the different aspects of auditory processing on cortical levels. The following section will address the conclusions regarding methodological aspects resulting from this thesis and the relevance for further scientific studies.

6.1. Methodological aspects

In this study, a two-dipole model, which was fitted to the overall condition of each participant, was used. Examining the present results, it could be possible that using a two-dipole model leads to a spatial distortion of the measured N1m component sources. Following Gutschalk et al. (2002), applying a four-dipole model could be helpful to better differentiate sources of the evoked potential in the auditory cortex, associated with the border area, including the HG and PT. Thus, such differentiation could reveal more information about the HG area, which is more sensitive to the sound level. Separating the HG and PT sources could also lead to more insights into the processing of the dynamic range adaption for the different sensitivity levels. It could also yield more profound insight into the effect of musicality between the two areas as well as stimulus sound-intensity dependence.

Another interesting methodological adaption for further studies could be to study a broader range of sound levels to see if the trends made out in the present data could be seen for a wider spectrum of different stimulus levels (following the fMRI study of Hall et al. (2001)).

To get a better understanding of the musical expertise effects and to reduce confounding effects, the next steps could include checking the stimuli-intensity effects for different musical skill levels by adapting the study design to include more ISI intervals (shorter) without varying the intensity level within a condition. Through this, the potential energy-changing confound on musical effects could be eliminated. Looking at the present results, other aspect that could be adapted would be to examine musical professionals (following Andermann et al. (2021)) and not only non-professional-musicians as well as separating the examination of different intensity levels of stimuli to gain further insights. This would methodologically include years of professional musical training and expertise on top of using tests of musicality such as the AMMA, which was used in this study.

6.2. New Insights - Scientific relevance

It is important to look at various correlations to further understand the processing of tone stimuli in the auditory cortex. The auditory pathway is very well known, but there are still a lot of unknowns regarding the processing of auditory information on cortical levels with respect to the many aspects of tone attributes in information processing. Based on prior knowledge, the current findings broaden the view even further using MEG, which is especially well suited for studying auditory activity. In light of the results from evaluating the effects of the N1m in the present study under the scope of the aspects mentioned above, the known stable ISI effects could be replicated, but further correlations and interactions did not yield statistically significant results. Visual inspection did indicate possible effects, in particular when looking at stimulus intensity, dynamic range adaption, and the impact of musicality on the amplitude height of the studied auditory component, but these effects did not possess statistical relevance. As mentioned above, a four-dipole model, which focuses on the HG component rather than the PT N1m component, could be beneficial, when further studying the aspects.

Looking at the results of the dynamic range adaption, specifically, concerning the studied stimulus property (intensity and dB SPL), the present findings did not yield new insights that were statistically significant. The current results indicate an adaption process, but this did not show a stable significant picture. This supports the conclusion that the adaption process was already finished at the ISIs used in this thesis. For further insight into these effects, studying a wider range, mainly including shorter ISI, should lead to new information and support prior research findings (see also section 1.2.2). It could also be beneficial to use greater inter-trail intervals when studying the adaption effect of tone trains since this would eliminate potential confounds of the repetition effect of tones over a longer period of time.

The musicality part of this study, which showed observable trends but no statistical significance, should not be entirely disregarded for further analysis. The present findings on trends of the N1m waveforms of the different musical skill levels are particularly interesting for further research. The contribution of this study to the research on musicality effects was to not only look at the various musical skill levels and their impact on the amplitude height but also to find out if the musical skill level also affects the adaption to repeated tone presentation. Interestingly the findings did not show any indication of such an effect. This could be the case since the N1m PT component, which the chosen N1m dipole focused on, might not be sensitive to musicality, but the N1m component based on the HG part may be. The relation between musical skill level, the intensity of the stimulus, and different interstimulus intervals did not reach statistical significance. For further studies, an adapted experiment design focusing on the HG N1m component and taking an inter-trail interval (mentioned above) into account as well as shorter ISIs may lead to further insights into these processes. It could also be gainful to study the musicality effects, which were focused on in this thesis, with a sample of professional musicians and not only divide the groups by tested musicality levels for more substantial effects. These adaptions to the study design present a promising approach to reach an even deeper understanding of the role musicality and expertise play in relation to different tone properties processed on cortical levels.

7. Summary

The present work focuses on the investigation of the magnetoencephalographic auditory N1m component, with the aim of investigating the different responses to stimulus attributes: intensity (decibels), temporal distance (interstimulus intervals), dynamic range adaptation, musicality, and their relationships to each other. For the data collection of neurophysiological auditory processing (N1m), magnetoencephalographic measurements were used to gain deeper insights. In addition, the assessment of the subjects' musicality was performed by means of a psychometric test. For the evaluation of the neurophysiological component, individual two-dipole models were created by means of source analysis. It is already widely known that stimulus attributes (intensity and temporal distance) affect the neuromagnetically measurable N1m. This effect could be replicated in the present study. Higher interstimulus intervals, as well as an increase in stimulus intensity, lead to an enhancement of the amplitude of the MEG component (N1m). Based on these findings, the dynamic range adaptation of the auditory N1m component was analyzed. For this purpose, within constant intensity tone trains (high vs. low) of three consecutive stimuli, the adaptation of the N1m component to stimulus repetition was investigated. Neither of the two stimulus intensity-modulated groups showed the expected stable decrease of amplitude, which would point toward the adaptation effect within the repeated stimulus series. The expected reduction in amplitude magnitude with increasing repetition of the identical stimulus could be visualized in some conditions but did not reach statistical significance. To determine the effects of different musicality on the auditory N1m, subjects in this study were divided into two groups with high and low musicality (high vs. low AMMA total score). Analysis of the two groups failed to detect any effect of musicality on the expression of the amplitude of the N1m. Finally, the interaction between dynamic range adaptation and musicality (high vs. low) was investigated. Within the two groups with different expressions of musical performance, the dynamic range adaptation of the individual stimulus sequences (within the high- vs. low-intensity group) was examined. Here, no adaptation effects of amplitude expression could be detected as well between the three consecutively presented tones within a stimulus intensity level.

Contrary to the original expectation, apart from the stimulus intensity effects as well as the interstimulus interval effects, no adaptation effects of the N1m component could be measured in the context of dynamic range adaptation. It is possible that the longer interstimulus intervals used in this study contribute to this negative result since, by this time, a possible adaptation might already have been completed. Also, the musicality of the subject groups did not lead to changes in the measured neuromagnetic component. Consequently, it can be concluded that musicality has no effect on components localized in the planum temporale. Thus, contrary to the pitch center in lateral Heschl's Gyrus, N1m in the planum temporale does not seem to be affected by the musicality. Consistent with these results, the interaction effects examined between dynamic range adaptation and musicality also showed no statistical relevance. In order to deeply understand the emergence and impact of adaptation effects in the context of dynamic range adaptation as well as the relevance of musicality, further research should focus on a stronger differentiation of the dipole model and the measured musicality performance.

Zusammenfassung

Die vorliegende Arbeit konzentriert sich auf die Untersuchung der magnetoenzephalographischen auditorischen N1m-Komponente, mit dem Ziel der Erforschung der unterschiedlichen Reaktionen auf die Stimulus-Attribute Intensität (Dezibel), zeitlicher Abstand (Interstimulus Intervalle), Dynamikbereichsadaptation und Musikalität, sowie deren Beziehungen zueinander. Für die Datenerhebung der neurophysiologischen Hörverarbeitung (N1m) wurden magnetoenzephalographische Messungen eingesetzt, um tiefere Einblicke zu gewinnen. Darüber hinaus wurde die Musikalität der Probanden mit Hilfe eines psychometrischen Tests bewertet. Für die Auswertung der neurophysiologischen Komponente wurden mittels Quellenanalyse individuelle Zwei-Dipol-Modelle erstellt. Es ist bereits weitgehend bekannt, dass Stimuluseigenschaften (Intensität und zeitlicher Abstand) die neuromagnetisch messbare N1m-Komponente beeinflussen. Dieser Effekt konnte in der vorliegenden Studie repliziert werden. Höhere Interstimulusabstände, sowie eine Erhöhung der Stimulusintensität, führen zu einer Verstärkung der Amplitude der MEG-Komponente (N1m). Basierend auf diesen Erkenntnissen wurde die Anpassung des dynamischen Bereichs der auditiven N1m-Komponente analysiert. Zu diesem Zweck wurde innerhalb von Tonfolgen konstanter Intensität (hoch vs. niedrig) von drei aufeinanderfolgenden Stimuli die Anpassung der N1m-Komponente an die Stimulus-Wiederholung untersucht. Keine der beiden stimulusintensitätsmodulierten Gruppen zeigte die erwartete stabile Amplitudenabnahme, was auf einen Adaptationseffekt innerhalb der wiederholten Stimulusserie hinweisen würde. Die erwartete Verringerung der Amplitudengröße mit zunehmender Wiederholung des identischen Reizes konnte in einigen Bedingungen sichtbar gemacht werden, erreichte aber keine statistische Signifikanz. Um die Auswirkungen unterschiedlicher Musikalität auf die auditive N1m zu bestimmen, wurden die Probanden in dieser Studie in zwei Gruppen mit hoher und niedriger Musikalität unterteilt (hoher vs. niedriger AMMA-Gesamtwert). Bei der Analyse der beiden Gruppen konnte kein Einfluss der Musikalität auf die Ausprägung

der Amplitude der N1m festgestellt werden. Schließlich wurde die Interaktion zwischen der Anpassung des dynamischen Bereichs und der Musikalität (hoch vs. niedrig) untersucht. Innerhalb der beiden Gruppen mit unterschiedlicher Ausprägung der musikalischen Darbietung wurde die Dynamikbereichsanpassung der einzelnen Stimulussequenzen (innerhalb der Gruppe mit hoher vs. niedriger Intensität) untersucht. Auch hier konnten keine Adaptationseffekte der Amplitudenausprägung zwischen den drei nacheinander dargebotenen Tönen innerhalb einer Stimulusintensitätsstufe festgestellt werden.

Entgegen der ursprünglichen Erwartung konnten neben den Stimulusintensitätseffekten sowie den Interstimulusintervalleffekten keine Adaptationseffekte der N1m-Komponente im Rahmen der Dynamikbereichsadaptation gemessen werden. Es ist möglich, dass die in dieser Studie verwendeten längeren Interstimulusintervalle zu diesem negativen Ergebnis beitragen, da zu diesem Zeitpunkt eine mögliche Adaptation bereits abgeschlossen sein könnte. Auch die Musikalität der Probandengruppen führte nicht zu Veränderungen in der gemessenen neu-magnetischen Komponente. Daraus lässt sich schließen, dass die Musikalität keinen Einfluss auf die im Planum temporale lokalisierten Komponenten hat. Im Gegensatz zum Tonhöhenzentrum im lateralen Heschl'schen Gyrus scheint die N1m im Planum temporale nicht von der Musikalität beeinflusst zu werden. In Übereinstimmung mit diesen Ergebnissen zeigten auch die untersuchten Interaktionseffekte zwischen der Anpassung des dynamischen Bereichs und der Musikalität keine statistische Relevanz. Um die Entstehung und Auswirkung von Adaptationseffekten im Kontext der Dynamikbereichsanpassung sowie die Relevanz der Musikalität besser zu verstehen, sollten sich weitere Forschungen auf eine stärkere Differenzierung des Dipolmodells und der gemessenen Musikalitätsleistung konzentrieren.

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A. Appendix

Table A.1.: Pooled AMMA groups - mean values

Variable	N	Min	Max	Mean	SD	95% CL low	95% CL high
amp1000 t1 l	27	-69.05	0.32	-9.23	13.14	-14.43	-4.03
amp1000 t1 r	27	-47.17	4.49	-8.48	10.89	-12.79	-4.17
amp1000 t2 l	27	-45.80	1.37	-8.00	9.56	-11.78	-4.22
amp1000 t2 r	27	-22.87	2.62	-6.11	6.47	-8.66	-3.55
amp1000 t3 l	27	-44.74	3.05	-7.44	10.10	-11.43	-3.44
amp1000 t3 r	27	-26.24	2.98	-4.56	6.55	-7.15	-1.97
amp1000 t5 l	27	-69.65	1.00	-15.32	16.67	-21.91	-8.72
amp1000 t5 r	27	-59.20	5.86	-10.44	14.93	-16.34	-4.53
amp1000 t6 l	27	-36.06	1.20	-11.04	10.79	-15.31	-6.77
amp1000 t6 r	27	-31.55	7.17	-8.25	10.10	-12.25	-4.26
amp1000 t7 l	27	-57.35	1.20	-11.66	12.34	-16.54	-6.78
amp1000 t7 r	27	-45.06	4.52	-7.30	10.28	-11.37	-3.23
amp2000 t1 l	27	-51.88	-2.07	-18.91	14.16	-24.51	-13.31
amp2000 t1 r	27	-50.01	1.16	-12.05	10.97	-16.39	-7.71
amp2000 t2 l	27	-51.56	3.14	-19.95	14.56	-25.71	-14.19
amp2000 t2 r	27	-43.62	4.12	-10.96	10.84	-15.25	-6.67
amp2000 t3 l	27	-49.04	0.10	-20.01	13.40	-25.32	-14.71
amp2000 t3 r	27	-47.10	6.27	-11.25	11.86	-15.94	-6.56
amp2000 t5 l	27	-70.53	-2.78	-28.89	17.65	-35.87	-21.91
amp2000 t5 r	27	-70.84	5.49	-18.55	17.43	-25.44	-11.66
amp2000 t6 l	27	-63.06	-2.61	-26.91	16.84	-33.57	-20.25
amp2000 t6 r	27	-50.26	6.85	-16.16	14.11	-21.75	-10.58
amp2000 t7 l	27	-57.80	-2.47	-26.17	15.56	-32.33	-20.02
amp2000 t7 r	27	-48.55	1.39	-15.56	12.52	-20.51	-10.61
amp4000 t1 l	27	-69.80	0.92	-31.12	19.95	-39.01	-23.23
amp4000 t1 r	27	-51.91	1.07	-22.48	14.76	-28.32	-16.64
amp4000 t2 l	27	-68.78	-4.67	-33.69	18.62	-41.05	-26.32
amp4000 t2 r	27	-64.43	2.76	-21.21	16.94	-27.91	-14.51
amp4000 t3 l	27	-65.68	-0.88	-32.12	18.02	-39.25	-24.99
amp4000 t3 r	27	-67.35	-0.61	-22.42	16.44	-28.92	-15.91
amp4000 t5 l	27	-88.14	1.93	-42.39	22.06	-51.12	-33.67
amp4000 t5 r	27	-95.67	-2.51	-29.56	22.13	-38.31	-20.80
amp4000 t6 l	27	-90.47	1.63	-42.37	22.94	-51.45	-33.30
amp4000 t6 r	27	-87.37	-3.24	-28.69	19.59	-36.44	-20.94
amp4000 t7 l	27	-75.47	-0.96	-41.88	21.40	-50.34	-33.41
amp4000 t7 r	27	-76.97	-1.38	-27.23	18.65	-34.61	-19.85

Table A.2.: AMMA group high - mean values

Variable	N	Min	Max	Mean	SD	95% CL low	95% CL high
amp1000 t1 l	12	-20.56	0.32	-6.55	5.74	-10.20	-2.90
amp1000 t1 r	12	-31.32	0.53	-9.79	9.21	-15.64	-3.94
amp1000 t2 l	12	-15.70	1.37	-6.10	5.58	-9.64	-2.56
amp1000 t2 r	12	-14.06	2.62	-7.14	4.97	-10.30	-3.98
amp1000 t3 l	12	-24.95	2.05	-6.22	8.05	-11.33	-1.10
amp1000 t3 r	12	-19.02	2.98	-4.89	6.13	-8.79	-1.00
amp1000 t5 l	12	-41.03	1.00	-13.53	14.65	-22.83	-4.22
amp1000 t5 r	12	-37.74	4.15	-11.65	14.30	-20.73	-2.56
amp1000 t6 l	12	-33.51	1.20	-10.59	11.56	-17.94	-3.24
amp1000 t6 r	12	-31.55	3.65	-10.29	10.81	-17.16	-3.42
amp1000 t7 l	12	-26.86	-1.04	-9.37	8.57	-14.81	-3.93
amp1000 t7 r	12	-23.55	4.35	-7.96	8.70	-13.49	-2.43
amp2000 t1 l	12	-37.78	-2.45	-17.66	11.14	-24.74	-10.59
amp2000 t1 r	12	-28.72	1.16	-11.29	8.38	-16.61	-5.96
amp2000 t2 l	12	-45.56	3.14	-17.98	14.27	-27.05	-8.91
amp2000 t2 r	12	-34.29	3.76	-11.75	10.18	-18.22	-5.28
amp2000 t3 l	12	-33.53	-0.93	-16.82	9.71	-22.99	-10.65
amp2000 t3 r	12	-36.56	1.34	-12.86	11.59	-20.22	-5.50
amp2000 t5 l	12	-49.16	-2.78	-27.27	15.92	-37.39	-17.15
amp2000 t5 r	12	-70.84	-0.53	-21.08	18.71	-32.96	-9.19
amp2000 t6 l	12	-53.52	-2.61	-25.69	16.05	-35.89	-15.50
amp2000 t6 r	12	-50.26	0.03	-16.41	14.75	-25.78	-7.04
amp2000 t7 l	12	-48.04	-2.47	-24.33	14.56	-33.58	-15.08
amp2000 t7 r	12	-48.55	-2.40	-17.21	12.24	-24.99	-9.44
amp4000 t1 l	12	-64.81	-1.01	-31.76	17.72	-43.02	-20.50
amp4000 t1 r	12	-47.17	1.07	-23.36	11.93	-30.93	-15.78
amp4000 t2 l	12	-62.69	-10.42	-34.42	16.21	-44.72	-24.12
amp4000 t2 r	12	-64.43	-8.22	-22.52	15.65	-32.46	-12.58
amp4000 t3 l	12	-56.40	-6.41	-31.36	15.30	-41.08	-21.64
amp4000 t3 r	12	-67.35	-8.15	-23.61	16.03	-33.79	-13.42
amp4000 t5 l	12	-88.14	-8.31	-45.10	22.61	-59.47	-30.73
amp4000 t5 r	12	-95.67	-5.08	-32.24	23.70	-47.30	-17.18
amp4000 t6 l	12	-90.47	-12.42	-45.55	22.30	-59.72	-31.38
amp4000 t6 r	12	-87.37	-4.40	-30.51	21.51	-44.18	-16.84
amp4000 t7 l	12	-72.04	-12.23	-44.54	18.20	-56.10	-32.98
amp4000 t7 r	12	-76.97	-12.70	-31.09	17.69	-42.33	-19.85

Table A.3.: AMMA group low - mean values

Variable	N	Min	Max	Mean	SD	95% CL low	95% CL high
amp1000 t1 l	15	-69.05	-0.41	-11.38	16.85	-20.71	-2.04
amp1000 t1 r	15	-47.17	4.49	-7.44	12.29	-14.24	-0.63
amp1000 t2 l	15	-45.80	-0.68	-9.52	11.81	-16.06	-2.98
amp1000 t2 r	15	-22.87	2.55	-5.28	7.52	-9.45	-1.11
amp1000 t3 l	15	-44.74	3.05	-8.41	11.67	-14.87	-1.95
amp1000 t3 r	15	-26.24	1.95	-4.29	7.07	-8.20	-0.37
amp1000 t5 l	15	-69.65	0.74	-16.75	18.50	-26.99	-6.50
amp1000 t5 r	15	-59.20	5.86	-9.47	15.84	-18.24	-0.69
amp1000 t6 l	15	-36.06	-0.01	-11.40	10.54	-17.23	-5.56
amp1000 t6 r	15	-30.41	7.17	-6.62	9.55	-11.91	-1.34
amp1000 t7 l	15	-57.35	1.20	-13.49	14.73	-21.65	-5.33
amp1000 t7 r	15	-45.06	4.52	-6.77	11.67	-13.24	-0.31
amp2000 t1 l	15	-51.88	-2.07	-19.90	16.50	-29.04	-10.76
amp2000 t1 r	15	-50.01	-1.39	-12.66	12.94	-19.83	-5.50
amp2000 t2 l	15	-51.56	-2.49	-21.52	15.10	-29.88	-13.16
amp2000 t2 r	15	-43.62	4.12	-10.33	11.65	-16.78	-3.87
amp2000 t3 l	15	-49.04	0.10	-22.57	15.61	-31.21	-13.92
amp2000 t3 r	15	-47.10	6.27	-9.96	12.32	-16.78	-3.14
amp2000 t5 l	15	-70.53	-3.44	-30.18	19.37	-40.91	-19.45
amp2000 t5 r	15	-53.88	5.49	-16.53	16.71	-25.78	-7.28
amp2000 t6 l	15	-63.06	-3.39	-27.89	17.95	-37.82	-17.95
amp2000 t6 r	15	-48.01	6.85	-15.97	14.10	-23.78	-8.16
amp2000 t7 l	15	-57.80	-4.37	-27.65	16.67	-36.88	-18.41
amp2000 t7 r	15	-46.21	1.39	-14.24	13.01	-21.45	-7.03
amp4000 t1 l	15	-69.80	0.92	-30.61	22.18	-42.89	-18.32
amp4000 t1 r	15	-51.91	0.73	-21.79	17.08	-31.25	-12.33
amp4000 t2 l	15	-68.78	-4.67	-33.10	20.89	-44.67	-21.53
amp4000 t2 r	15	-55.91	2.76	-20.16	18.39	-30.34	-9.98
amp4000 t3 l	15	-65.68	-0.88	-32.72	20.45	-44.05	-21.40
amp4000 t3 r	15	-55.23	-0.61	-21.47	17.26	-31.03	-11.91
amp4000 t5 l	15	-72.70	1.93	-40.23	22.15	-52.49	-27.96
amp4000 t5 r	15	-72.10	-2.51	-27.41	21.38	-39.25	-15.57
amp4000 t6 l	15	-78.05	1.63	-39.83	23.89	-53.06	-26.60
amp4000 t6 r	15	-57.81	-3.24	-27.23	18.56	-37.51	-16.95
amp4000 t7 l	15	-75.47	-0.96	-39.75	24.07	-53.08	-26.41
amp4000 t7 r	15	-63.55	-1.38	-24.14	19.42	-34.89	-13.38

Table A.4.: Statistical Analysis N1m – Amplitude Modulation – 1000 vs 2000

Source	df	F-Value	p-Value
Intenstiy	$1, 25$	35.34	$<.0001^{**}$
Hemi	$1, 25$	15.80	0.0005^{**}
Intensity*Hemi	$1, 25$	4.95	0.0353^{*}

Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, Hemi = hemisphere

Table A.5.: Statistical Analysis N1m – Interstimulus Interval 1000 vs 2000

Source	df	F-Value	p-Value
ISI*Intensity	$1, 25$	12.01	$<.0019^{*}$
ISI*Hemi	$1, 25$	32.68	$<.0001^{**}$
ISI*Hemi*Intensity	$1, 25$	0.02	0.8873

Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$; ISI = Interstimulus Intervals, Intensity = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

Table A.6.: Statistical Analysis N1m & DRA – 1000 vs 2000

Source	df	F-Value	p-Value
DRA	$2, 50$	10.00	0.0002^{**}
DRA*Intensity	$2, 50$	3.18	0.0499^{*}
DRA*Hemi	$2, 50$	1.37	0.2646
DRA*Intensity*Hemi	$2, 50$	1.80	0.1755

Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$; DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity-modulated stimuli, Hemi = Hemisphere

Table A.7.: Statistical Analysis N1m & DRA – Interstimulus Interval– 1000 vs 2000

Source	df	F-Value	p-Value
DRA*ISI	$2, 50$	1.70	0.1926
DRA*ISI*Intensity	$2, 50$	0.93	0.4015
DRA*ISI*Hemi	$2, 50$	1.44	0.2464
DRA*ISI*Intensity*Hemi	$2, 50$	0.37	0.6947

Note. $^{*}p$-Wert $< .05$, $^{**}p$-Wert $< .01$;
ISI = Interstimulus Intervals, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Group = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

Table A.8.: Statistical Analysis Musicality – Amplitude Modulation – 1000 vs 2000

Source	df	F-Value	p-Value
AMMA	$1, 25$	0.02	0.8762
AMMA*Intensity	$1, 25$	0.33	0.5721
AMMA*Hemi	$1, 25$	2.99	0.0961
AMMA*Intensity*Hemi	$1, 25$	0.01	0.8805

Note. * p-Wert $< .05$, ** p-Wert $< .01$; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.9.: Statistical Analysis Musicality – Interstimulus Interval – 1000 vs 2000

Source	DF	F-Value	p-Value
AMMA*ISI	$1, 25$	0.00	0.9542
AMMA*ISI*Intensity	$1, 25$	0.11	0.7464
AMMA*ISI*Hemi	$1, 25$	0.00	0.9756
AMMA*ISI*Intensity*Hemi	$1, 25$	0.09	0.7641

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.10.: Statistical Analysis Musicality & DRA – Amplitude Modulation – 1000 vs 2000

Source	df	F-Value	p-Value
DRA*AMMA	$2, 50$	0.18	0.8332
DRA*Intensity*AMMA	$2, 50$	0.35	0.7060
DRA*Hemi*AMMA	$2, 50$	0.84	0.4383
DRA*Intensity*Hemi*AMMA	$2, 50$	3.26	0.0460

Note. * p-Wert $< .05$, ** p-Wert $< .01$; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity stimuli, Hemi = Hemisphere

Table A.11.: Statistical Analysis Musicality & DRA – Interstimulus Interval – 1000 vs 2000

Source	df	F-Value	p-Value
DRA*AMMA*ISI	$2, 50$	0.45	0.6377
DRA*ISI*Intensity*AMMA	$2, 50$	0.78	0.4652
DRA*ISI*Hemi*AMMA	$2, 50$	3.26	0.0468*
DRA*ISI*Intensity*Hemi*AMMA	$2, 50$	3.50	0.0379

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.12.: Statistical Analysis N1m – Amplitude Modulation – 2000 vs 4000

Source	df	F-Value	p-Value
Intenstiy	$1, 25$	62.39	<.0001**
Hemi	$1, 25$	20.72	0.0001**
Intensity*Hemi	$1, 25$	7.85	0.0097**

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, Hemi = hemisphere

Table A.13.: Statistical Analysis N1m – Interstimulus Interval 2000 vs 4000

Source	df	F-Value	p-Value
ISI*Intensity	$1, 25$	4.84	0.0372*
ISI*Hemi	$1, 25$	1.62	0.2154
ISI*Hemi*Intensity	$1, 25$	0.60	0.4469

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Intervals, Intensity = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

Table A.14.: Statistical Analysis N1m & DRA – 2000 vs 4000

Source	df	F-Value	p-Value
DRA	$2, 50$	1.31	0.2780
DRA*Intensity	$2, 50$	3.77	0.0298*
DRA*Hemi	$2, 50$	3.14	0.0520
DRA*Intensity*Hemi	$2, 50$	0.76	0.4737

Note. * p-Wert $< .05$, ** p-Wert $< .01$; DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity-modulated stimuli, Hemi = Hemisphere

Table A.15.: Statistical Analysis N1m & DRA – Interstimulus Interval– 2000 vs 4000

Source	df	F-Value	p-Value
DRA*ISI	$2, 50$	1.70	0.1926
DRA*ISI*Intensity	$2, 50$	0.93	0.4015
DRA*ISI*Hemi	$2, 50$	1.44	0.2464
DRA*ISI*Intensity*Hemi	$2, 50$	0.37	0.6947

Note. * p-Wert $< .05$, ** p-Wert $< .01$;
ISI = Interstimulus Intervals, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Group = high vs. low intensity-modulated stimuli, Hemi = Hemisphere

Table A.16.: Statistical Analysis Musicality – Amplitude Modulation – 2000 vs 4000

Source	df	F-Value	p-Value
AMMA	$1, 25$	0.05	0.05
AMMA*Intensity	$1, 25$	0.33	0.5721
AMMA*Hemi	$1, 25$	0.41	0.5284
AMMA*Intensity*Hemi	$1, 25$	0.07	0.07

Note. * p-Wert $< .05$, ** p-Wert $< .01$; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.17.: Statistical Analysis Musicality – Interstimulus Interval – 2000 vs 4000

Source	DF	F-Value	p-Value
AMMA*ISI	$1, 25$	0.92	0.3467
AMMA*ISI*Intensity	$1, 25$	2.38	0.1352
AMMA*ISI*Hemi	$1, 25$	0.94	0.3404
AMMA*ISI*Intensity*Hemi	$1, 25$	0.57	0.4567

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.18.: Statistical Analysis Musicality & DRA – Amplitude Modulation – 2000 vs 4000

Source	df	F-Value	p-Value
DRA*AMMA	2, 50	0.02	0.9833
DRA*Intensity*AMMA	2, 50	0.66	0.5203
DRA*Hemi*AMMA	2, 50	3.38	0.0419*
DRA*Intensity*Hemi*AMMA	2, 50	1.52	0.2284

Note. * p-Wert $< .05$, ** p-Wert $< .01$; AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high- vs. low-intensity stimuli, Hemi = Hemisphere

Table A.19.: Statistical Analysis Musicality & DRA – Interstimulus Interval – 2000 vs 4000

Source	df	F-Value	p-Value
DRA*AMMA*ISI	2, 50	0.06	0.2699
DRA*ISI*Intensity*AMMA	2, 50	0.43	0.6526
DRA*ISI*Hemi*AMMA	2, 50	0.03	0.9704
DRA*ISI*Intensity*Hemi*AMMA	2, 50	0.90	0.4130

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, AMMA = AMMA Group - high vs. low musicality scores, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli, Hemi = Hemisphere

Table A.20.: Statistical Analysis N1m – all ISI – low vs high – left hemisphere

Source	df	F-Value	p-Value
Intensity	1, 26	6.31	<.0001**
ISI	2, 52	63.34	<.0001**
Intensity*ISI	2, 52	10.19	<.0002**

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, ISI = Interstimulus Interval

Table A.21.: Statistical Analysis N1m & DRA – all ISI – low vs high – left hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	2.44	0.0967
DRA*Intensity	$2, 52$	5.74	0.0056**
DRA*ISI	$4, 104$	3.33	0.0131*
DRA*Intensity*ISI	$4, 104$	0.44	0.7793

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Table A.22.: Statistical Analysis N1m – 1000 vs 2000 – low vs high – left hemisphere

Source	df	F-Value	p-Value
Intenstiy	$1, 26$	45.66	<.0001**
ISI	$1, 26$	55.94	<.0001**
Intensity*ISI	$1, 26$	10.71	0.0030

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, Hemi = hemisphere

Table A.23.: Statistical Analysis N1m & DRA – 1000 vs 2000 – low vs high – left hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	6.70	0.0026**
DRA*Intensity	$2, 52$	5.65	0.0060**
DRA*ISI	$2, 52$	2.42	0.0987
DRA*Intensity*ISI	$2, 52$	0.46	0.6357

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Table A.24.: Statistical Analysis N1m – 2000 vs 4000 – low vs high – left hemisphere

Source	df	F-Value	p-Value
Intenstiy	$1, 26$	77.09	<.0001**
ISI	$1, 26$	31.57	0.0001**
Intensity*ISI	$1, 26$	3.35	0.0785

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, ISI = Interstimulus Interval

Table A.25.: Statistical Analysis N1m & DRA – 2000 vs 4000 – low vs high – left hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	0.67	0.5166
DRA*Intensity	$2, 52$	6.45	0.0031**
DRA*ISI	$2, 52$	1.37	0.2639
DRA*Intensity*ISI	$2, 52$	1.00	0.3747

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Table A.26.: Statistical Analysis N1m – all ISI – low vs high – right hemisphere

Source	df	F-Value	p-Value
Intenstiy	$1, 26$	17.51	$<.0003$*
ISI	$2, 52$	34.81	0.0001*
Intensity*ISI	$2, 52$	8.50	0.0006

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, ISI = Interstimulus Interval

Table A.27.: Statistical Analysis N1m & DRA – all ISI – low vs high – right hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	6.72	0.0025**
DRA*Intensity	$2, 52$	0.64	0.5324
DRA*ISI	$4, 104$	1.06	0.3796
DRA*Intensity*ISI	$4, 104$	0.65	0.6284

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Table A.28.: Statistical Analysis N1m – 1000 vs 2000 – low vs high – right hemisphere

Source	df	F-Value	p-Value
Intenstiy	$1, 26$	11.16	0.0025**
ISI	$1, 26$	15.86	0.0005**
Intensity*ISI	$1, 26$	7.78	0.0097**

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, ISI = Interstimulus Interval

Table A.29.: Statistical Analysis N1m & DRA – 1000 vs 2000 – low vs high – right hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	9.70	0.0003**
DRA*Intensity	$2, 52$	0.23	0.7957
DRA*ISI	$2, 52$	0.99	0.3788
DRA*Intensity*ISI	$2, 52$	0.99	0.3802

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Table A.30.: Statistical Analysis N1m – 2000 vs 4000 – low vs high – right hemisphere

Source	df	F-Value	p-Value
Intenstiy	$1, 26$	25.59	<.0001**
ISI	$1, 26$	27.38	<.0001**
Intensity*ISI	$1, 26$	1.07	0.3102

Note. * p-Wert $< .05$, ** p-Wert $< .01$; Intensity = high- vs. low-intensity-modulated stimuli, Hemi = hemisphere

Table A.31.: Statistical Analysis N1m & DRA– 2000 vs 4000 – low vs high – right hemisphere

Source	df	F-Value	p-Value
DRA	$2, 52$	2.61	0.3102
DRA*Intensity	$2, 52$	1.10	0.3370
DRA*ISI	$2, 52$	0.31	0.7333
DRA*Intensity*ISI	$2, 52$	0.25	0.7803

Note. * p-Wert $< .05$, ** p-Wert $< .01$; ISI = Interstimulus Interval, DRA = Dynamic Range Adaption - Differences within tones sequences (1,2,3/ 5,6,7), Intensity = high vs. low intensity stimuli

Eidesstattliche Versicherung

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   Dynamic range adaption of the N1m component elicited by intensity-modulated tones and its relation to musicality

   handelt es sich um meine eigenständig erbrachte Leistung.
2. Ich habe nur die angegebenen Quellen und Hilfsmittel benutzt und mich keiner unzulässigen Hilfe Dritter bedient. Insbesondere habe ich wörtlich oder sinngemäß aus anderen Werken übernommene Inhalte als solche kenntlich gemacht.
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Ludwigsburg, den 06. January 2023 Kristin Held

Acknowledgements

First of all, I would like to thank PD Dr. André Rupp for the support and for providing continuous guidance throughout the process of this project. Thank you very much for all the knowledge you shared with me as well as the repeated feedback throughout the whole process. Throughout the years, you have fundamentally shaped my view of research and the process of scientific work. Working in your section and having you as my supervisor has formed and deepened my enthusiasm for neuroscience research even further. I also really appreciated the pleasant atmosphere where you guided me so positively and always made me feel confident in my abilities after the many discussions and conversations. Thank you for sharing your passion with me, allowing me to further deepen my skills by conducting this project, and always inspiring me to always look for the next step. I could not have wished for a better supervisor for my dissertation.

A thank you to my second supervisor, PD Dr. Eugen Diesch, especially for providing guidance in the setup of my project as well as for the feedback in various discussions. I would also like to thank the following people for helping during the data collection process. A special thank you to the members of the MEG-Lab, Mrs. Heide Rogatzki, Mrs. Barbara Burghardt, and Mrs. Esther Tauberschmidt.

A big thank you to my family for all the support you have shown me through this research and writing process over the last few years. I could not have done it without you! A special thanks to my parents, who have always supported me unconditionally, keep encouraging me, and always have my back. To my husband, who always supported and listened to me and always watched out for me so that I had all the strength to finish my thesis. To my brother, who keeps inspiring me and always is there when I need an open ear. And my grandparents, who always believe in me. Thank you to all of you who had to endure my stresses and moans while writing this thesis. I could not have wished for a more supportive and loving family.