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Separating Post-perceptual Processes from Auditory Awareness: An Electrophysiological Study With a No-response Task

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Andréas Fjordstig

Supervisor: Rasmus Eklund
Examiner: Antti Revonsuo

Authors Note

Andréas Fjordstig, School of Bioscience, University of Skövde.

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Correspondence concerning the paper can be addressed to Andreas.fjordstig@gmail.com

Abstract

Two theories of consciousness have different ideas about when consciousness happens and what neural processes enable conscious experience. The recurrent processing theory supports an early onset of consciousness caused by recurring loops of information between sensory areas. Contrary to this belief, the global workspace theory claims that consciousness appears later, through global recurrent loops of information between sensory and higher order brain areas such as the visual cortex and frontoparietal areas. Electrophysiological studies have found an event-related negativity arising in primary visual areas around 200 *ms* that correlates to awareness. This activity suits the predictions of an early onset of consciousness made by the recurrent processing theory. It is followed by a later positive amplitude appearing around 400 *ms*. This activity is in line with predictions made by the global workspace theory. The current study transition from visual to auditory awareness research in order to find the neural correlates of consciousness in audition. A sound detection task with tones calibrated to each participant's threshold value was used in the experiment and two electrophysiological measurements of auditory awareness were found. An auditory awareness negativity that appears around 200 *ms* after stimulus onset and a late positivity appearing around 400 *ms*. Researchers disagree about if these event-related potentials correlate with awareness or unrelated cognitive mechanisms. In order to solve this problem, the current experiment was devised to test if they were affected by response conditions. A no-response paradigm with reversed response conditions was used to separate pre- and post-conscious mechanisms from the auditory awareness negativity and the late positivity. Results showed that auditory awareness negativity was independent of response condition and thus free from post-perceptual processes. The late positivity amplitude seems to be dependent on response condition but the result was inconclusive.

Keywords: auditory awareness negativity, late positivity, event-related potentials, recurrent processing theory, global workspace theory, neural correlates of consciousness

Introduction

Consciousness remains one of the great mysteries ever known to man. In the past three decades, an ongoing conflict in consciousness research has revolved around the question: Is consciousness the pure experience of what it is like to be conscious (phenomenal consciousness) or is it the reasoning about and reporting of our experiences (access consciousness; Block, 1995, 2007; Koivisto & Revonsuo, 2010; Lamme, 2010)? According to Lamme (2010), consciousness arises from early activity in our brain that is unrelated to mechanisms enabling the report of our experiences. He argues that there are qualitative aspects of what it is like to be conscious that precede access and report. This theory is known as *recurrent processing theory* (Lamme & Roelfsema, 2000). Baars, (2005) rejects this theory, arguing that early activity is correlated to pre-conscious mechanisms. He claims that consciousness arises later together with important attentional mechanisms in a global brain activation. This theory is called *the global workspace theory*.

Consciousness researchers have tried to provide insights into this conflict by searching for the neural correlates of consciousness (NCC; Revonsuo, 2009). An NCC is the minimal combined neural activity necessary and sufficient for a conscious experience (Crick & Koch, 1990). The most common way of measuring an NCC is to device a task with an aware and an unaware condition which can be compared to provide the difference in brain activity. This method is known as a contrastive analysis (Aru, Bachmann, Singer, & Melloni, 2012). Previous research in vision has used electrophysiological measurements in the search for the NCC and found two event-related potentials (ERPs) of visual awareness: An early negative peak appearing around 200 ms called *visual awareness negativity* (VAN) and a later positive peak appearing around 400 ms called *late positivity* (LP) (Luck, 2014; Koivisto & Revonsuo, 2003; Koivisto, Salminen-Vaparanta, Grassini, & Revonsuo, 2016). Recurring processing theory claims that VAN correlates with early conscious activity proposed by the theory while global workspace theory claim that LP is in line with their predictions of a later onset of consciousness (Lamme, 2010).

Koivisto et al. (2016) conducted an experiment where they tried to separate post-perceptual processes of visual awareness from VAN and LP. To achieve this separation they used a no-response paradigm which investigates if the answering process itself confounds the correlates being studied (Tsuchiya, Wilke, Frässle, & Lamme, 2015). Koivisto et al. (2016)

created two opposite response conditions: a response condition where the participants pressed a button if they perceived the stimulus and abstained answering if no stimulus was perceived, and a no-response condition where participants abstained the button press if the stimulus was perceived and pressed the button when no stimulus was perceived. Activation in each condition was compared to reveal if the response requirement affected the activation. The comparison between conditions revealed that LP, previously suggested to play a central role in consciousness by global workspace theory (Dehaene, 2014), differed in activation between response conditions. In other words, LP was found to be related to post-perceptual processes. VAN activation did not differ between conditions as predicted by the recurrent processing theory. This leads to the conclusion that visual awareness emerges prior to LP (Koivisto et al., 2016; Lamme & Roelfsema, 2000).

Previous NCC research has mainly been investigating the NCCs in vision (Koivisto & Revonsuo, 2010). But in recent years there has been an increased interest in NCC research of auditory awareness (Dykstra, Cariani, & Gutschalk, 2017). Similar ERPs previously found in vision (VAN and LP) have been found in audition as well: an early negative amplitude appearing around 200 ms after stimulus onset called auditory awareness negativity (AAN) and a later positive amplitude appearing around 400 ms called late positivity (LP)(Eklund & Wiens, 2019; Parasuraman & Beatty, 1980; Squires, Hillyard, & Lindsay, 1973).

The purpose of this study is to search for the previously reported candidates of awareness in audition and investigate if they are affected by response conditions (confirming the perception of a stimulus by pressing a button or confirming by doing nothing). We used a sound detection task where a sound was calibrated to each subjects threshold value. This created an aware condition (participants perceived the sound) and an unaware condition (participants did not perceive the sound) that could be compared through contrastive analysis. Two response conditions were added (*respond-if-aware* and *respond-if-unaware*) in order to test if the ERPs found in the response conditions differed from one another. The study works with two hypotheses:

1. We predict an early amplitude difference for aware trials minus unaware trials, in the early time interval (160-260 *ms*), this difference will be referred to as AAN. This negativity does not differ between the response condition and the no-

response condition. This negativity is observed for the response condition. This negativity is observed for the no-response condition.

2. We predict a late amplitude difference for aware trials minus unaware trials for the late interval (350-550 *ms*), this difference will be referred to as LP. This positivity is larger for the response condition than the no-response condition. This positivity is observed for the response condition. This positivity is observed for the no-response condition.

In order to provide sufficient background to understand the study I will move forward accordingly: A background on the concepts of consciousness will be provided to give an understanding of the philosophical aspects of the study. This will be followed by a section explaining how it is possible to measure consciousness. Thereafter, the neural structures and functions that underlie those measurements will be presented to get a holistic picture from the philosophical to the practical. Further, the present conflict between the two theories of consciousness mentioned above and how the theories relate to the neural measurements investigated will be presented. The introduction will end by describing how the no-response paradigm can be used to separate unrelated cognitive processes from measurements of conscious experience.

Consciousness

Consciousness continues to elude our understanding and remains one of the great mysteries of science. Most notorious is the hard problem of consciousness: Why do we have subjective experiences instead of unfelt states? Descartes answered this question by dividing the world into two substances. A material substance (the body) that would serve us while we live and a spiritual substance (the soul) that would live on after we perished (Descartes, 1984). The soul made a rich, qualitative experience possible. Modern philosophy of consciousness is mostly based on the monistic standpoint that the world consists of matter alone (Bennett, Hacker, & Bennett, 2003). Therefore, in this thesis, I shall assume that everything is matter and that consciousness resides in the brain.

Although the modern science of consciousness is divided into different theories and the concept of consciousness is vague and hard to define, some aspects of consciousness have mostly been agreed upon (Revonsuo, 2009). This thesis will present three concepts of consciousness: phenomenal, access, and reflexive consciousness (Block, 2005; Wiens, 2007). To get a quick feel for these concepts, imagine driving a car. You are constantly experiencing what it is like to be driving (phenomenal consciousness), your attention is shifting between important information such as road signs and other cars (access consciousness), and you can reflect about the situation of driving the car (reflexive consciousness).

Concepts of consciousness

Phenomenal Consciousness

Phenomenal consciousness is the experience of what-it-is-like to be an organism (Block, 1995; Nagel, 1974). The concept is related to the term qualia which describes the subjective, qualitative aspects of consciousness such as experiencing the taste of ice cream, the color red or dulling pain (Lewis, 1956). Although phenomenal consciousness composes qualia, phenomenality does not describe consciousness of any specific content (Block, 1995). Chalmers (1996) describes a thought experiment that gives a deeper understanding of phenomenal consciousness called *the philosophical zombie*. Imagine a person that is identical to you in every way but is devoid of inner experiences. He or she reacts to pain but does not feel the sensation, eats the ice cream without the taste, registers the color of red without any qualitative aspect. It is nothing to be the philosophical zombie, therefore, it lacks phenomenal consciousness. ”Take away the feel of phenomenality and you take away phenomenality itself.” (Revonsuo, 2009, p 70).

Phenomenal consciousness contains vast amounts of information while our attentional system, that enables access to conscious sensations, is limited (Block, 1995). Block (2005) describes this as a consciousness that overflows attention. However, despite the limited access to our experiences, we get the feeling of a rich and detailed reality. Revonsuo (2009) describes the phenomenal information as a field of consciousness including everything we perceive at any given moment. In the center of this field lies a focal point where all attended information is accessed. In the periphery outside the focus of attention lies all experience that is currently inaccessible. Think of a busy city street filled with impressions. When moving through the crowd you are unable to focus on every face, car, building or store that your senses register. You only attend a couple of objects at any given time. Yet, you get the feel of experiencing a high-resolution motion picture. The line between the center of consciousness and its periphery is fuzzy and creates the illusion of experiencing everything clearly (Revonsuo, 2009). This is sometimes called the refrigerator light illusion which describes consciousness as the lamp in a refrigerator (Blackmore, 2003) When you open the refrigerator door it seems like the light was already on. No matter how fast you try to open the door you will always get the same illusion. In consciousness, you get the feeling of a vivid representation of reality (that the light is always on) beyond the center of attention. But as you try to inspect the quality of the peripheral zone your center of attention (the refrigerator lamp) changes and you get a vivid representation. Thus, it is impossible to subjectively assess the quality of the peripheral zone.

Access Consciousness

Access consciousness makes phenomenal experiences reportable. As described by Block (2005) access consciousness contains information used for reasoning, decision-making, and voluntary direction of action. In a vast neural system consisting of multiple specialized networks a process that integrates the flow of information is needed (Wiens, 2007). That process is called access consciousness. Just like a computer the processing power of the mind is limited to a few programs at the time (Lamme, 2010). The limit of working memory forces information to compete in order to reach the attentional system in our brain. When it reaches this global activation it goes beyond pure phenomenal consciousness to be accessed and reported (Revonsuo, 2009). Such a process is a premise for reasoning and rational control of action (Block, 1995).

Reflexive consciousness

Another relevant concept that is often confused with access consciousness is reflexive consciousness. It can be described as the awareness of phenomenal experiences (Wiens, 2007). Both access and reflexive consciousness describe report of phenomenal experiences and thus are similar in their main function. But access consciousness describes moment to moment experiences while reflexive consciousness is more about reflection about a series of events (Rosenthal, 2002). This paper will focus on access and phenomenal consciousness since they are most relevant to the experiment.

Measuring consciousness

Contrastive analysis and the threshold task

To be able to measure consciousness, tasks have been devised that separates aware and unaware conditions (Aru et al., 2012). In the present study, we will use a sound detection task to measure auditory awareness. The method is developed from the common threshold task, where the intensity of a stimulus is calibrated to a level where it is sometimes detected and sometimes not (Koivisto & Revonsuo, 2010). Results can then be analyzed to reveal differences in brain activation between the cases where participants perceived the task and cases where participants did not perceive the task. In a threshold sound detection task, a stimulus is presented with background noise or calibrated to a level where it is perceived 50 percent of the time (Dykstra et al., 2017). The task manipulates awareness by making it harder or easier to detect the stimulus. Hillyard, Squires, Bauer, & Lindsay (1971) conducted a sound detection task while investigating auditory awareness. The task was to detect a tone presented in different intensity from background noise. EPRs were recorded from the four different outcomes: detected signals (hits), failures to detect signals (misses), incorrect reports of signal presence (false alarms), and correct reports of signal absence (correct rejections). Hillyard et al. (1971) found evidence for a late positive peak at the P3 time window (and traces of an early negative peak. Later experiments have since confirmed the presence of P3 in audition (LP) and found evidence for an early negativity termed auditory awareness negativity (AAN; Eklund & Wiens, 2019).

Electroencephalography and Event-related potentials

Our brain produces constant electrical activity resulting mainly from tiny dipoles created by the activity of our neurons (Luck, 2014). Using electroencephalography (EEG), researchers are able to measure this fluctuating activity by placing electrodes on the scalp or directly onto the brain (mostly performed on animals). Electrical voltage is measured, amplified and plotted to provide the changes in voltage over time (Berger, 1929). These electrical currents travel almost instantaneously through the meninges and the skull giving EEG a temporal resolution of milliseconds. The ability to measure changes in voltage with high temporal resolution together with a relatively low cost is what makes the EEG stick out from other brain measuring tools (Luck, 2014).

EEG measurements corresponding to a specific event is called event-related potentials (ERPs). *Event-related* referring to an activity that corresponds to a time-locked event. *Potential* referring to electrical potential or voltage (Luck, 2014). ERP waveforms are usually presented in the form of a graph. The positive hills and negative valleys of the waveform are called *peaks.* Peaks usually receive a letter indicating their amplitude, P stands for positive and N for negative. The number associated with P or N either indicate the timespan for when a peak begins (e.g N170) or in which order the peak appears (N1, N2, P3, etc).

As reviewed by Luck (2014), to calculate an ERP, EEG recordings from each electrode are amplified and converted to digital information by a digitalization computer. The EEG response from one trial (an epoch) does not give us an ERP. To separate the relevant signals from noise, several epochs have to be averaged together. Because the noise varies in amplitude it will cancel out when averaging across epochs and leave only the relevant signal (the ERP). The EEG activity from two conditions (aware vs unaware) can be compared to provide ERP waveforms related to awareness. This method is called contrastive analysis (Aru et al., 2012).

Although there are benefits to the EEG it should be noted that it is a rather coarse instrument. The initial measurement is a mix-up of many different neural processes and needs to be filtered to provide relevant information (Luck, 2014). It is also prone to noise (statics), mostly from unrelated brain activity, but also from magnetic fields in the environment such as computers, cell phones and other instruments that generate electrical fields (Luck, 2014). The relevant components are so small compared to the noise that a large number of trials has to be collected to generate a result. Further, the location where the electrical activity is coming from is incredibly hard to determine from ERP technology and other brain measuring tools is usually preferred.

Event-related Potentials of Vision and Audition

Electrophysiological studies searching for the NCC in vision have repeatedly found two ERPs that correlate to visual awareness: an occipital-temporal negativity appearing around 200 *ms* after stimulus onset (visual awareness negativity, VAN) and a parietal positivity appearing at 300 *ms* after stimulus onset in the P3 time window (late positivity, LP; Koivisto & Revonsuo, 2010). These ERPs have been extensively studied in contrast to auditory awareness ERPs which have received limited attention (Babiloni, Vecchio, Miriello, Romani, & Rossini, 2005; Eklund & Wiens, 2018, 2019; Schankin & Wascher, 2007; Sergent, Baillet, & Dehaene, 2005).

Koivisto & Revonsuo (2010) conducted a review of 39 recent ERP studies trying to find the correlates of subjective visual awareness. Their findings suggest that VAN is the most reliable and consistent ERP followed by LP. They define VAN as “the negative difference between ERPs to stimuli that enter visual awareness and to stimuli that do not enter” (Koivisto & Revonsuo, 2010, P. 925). In other words, VAN has been shown to consistently differ as a function of visual awareness.

The peak at around 400 ms in the P3 time window (LP) usually, but not always, follows VAN (Koivisto et al., 2008; Koivisto, Revonsuo, & Lehtonen, 2006). The late appearance of LP might not directly relate to visual awareness but indicate a correlation with post-perceptual mechanisms (Koivisto & Revonsuo, 2010). This would support theories that favor early recurrent processing as a basis for conscious perception (Lamme, 2010). However, this is disputed by other authors who have observed cases where only LP correlate with visual awareness (Lamy, Salti, & Bar-Haim, 2009; Niedeggen, Wichmann, & Stoerig, 2001; Salti, Bar-Haim, & Lamy, 2012). They claim that LP is the earliest correlate of visual awareness and that earlier activation indicates pre-perceptual processes. Koivisto & Revonsuo (2010) argue against this claim, suggesting that the large component of LP is easily detected and that insufficient sensitivity in experimental methods might have missed the smaller VAN component in favor to their results.

VAN and LP have also been found in auditory awareness research (Dykstra et al., 2017). Eklund & Wiens, (2019) conducted an experiment with the goal of establishing the ERP correlates of auditory awareness. They modeled their study after previous ERP studies (Hillyard et al., 1971; Parasuraman & Beatty, 1980; Squires et al., 1973) that used a sound detection task to separate measure auditory awareness. Subjects were given a grading scale to report their experiences. They found evidence of a negative amplitude difference similar to VAN in vision they call “auditory awareness negativity” (AAN) and the P3 amplitude ERP (LP).

To understand what we are measuring, it is important to provide the structural and functional background of the auditory system and the processes involved in awareness.

Underlying Structures and Processes of Auditory Awareness

Neural Structure and Function of Audition

Our hearing provides a rich representation of the world and gives us remarkable abilities. From the changes in pressure created by vibrations from different sound sources, we are able to determine the relative distance to the source and discriminate between a multitude of objects from the background noise (Moore, 2012). The main feature of hearing might be the extent of its sensitivity to a multitude of diverse events in the environment (Dykstra et al., 2017). It also enables us to communicate efficiently through speech and appreciate the wonderful sensation of music. Like touch, but unlike vision, hearing remains sensitive to external events during sleep and can effectively initiate the transition to wakefulness (Dykstra et al., 2017).

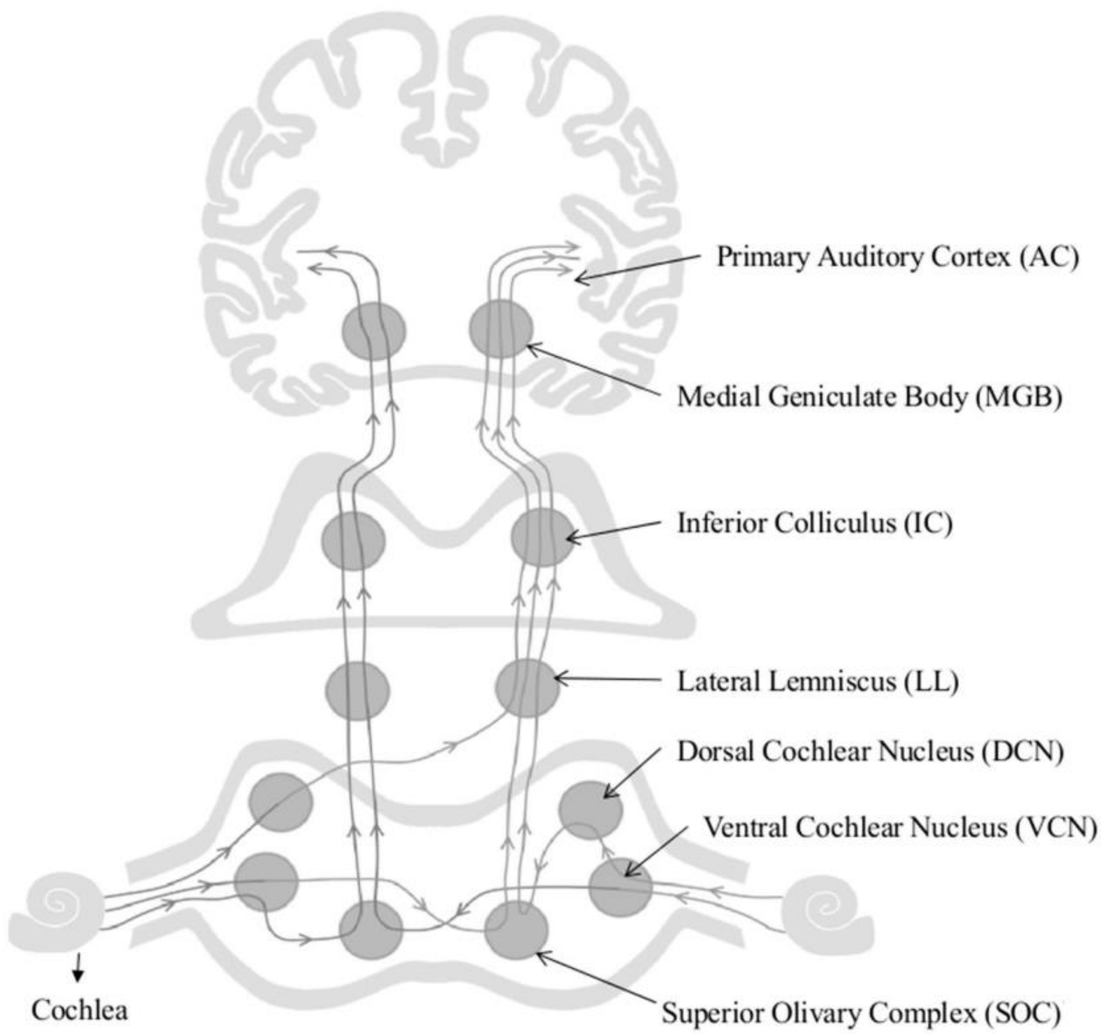

Figure 1. Schematic diagram of the auditory pathway. The diagram shows the ipsi- and contralateral pathways from the cochlea to the auditory cortex. Modified from Jayakody, Friedland, Martins, & Sohrabi, 2018.

Despite its versatileness, considerably less is known about the nature of hearing compared to the visual system (King & Nelken, 2009). This is mostly due to the fact that there has been greater effort during several more decades to study vision. Recent years have seen an increase in auditory research, but despite a large increase in auditory studies, it has proven difficult to unravel the workings of the auditory system (Dykstra et al., 2017). How does the auditory system combine complex auditory information into coherent percepts? How is it possible to know the direction of a sound? How are we able to discriminate the sound of a familiar voice through the crowd? How do audition and vision collaborate to integrate information? A lot of questions remain to be answered about the auditory system.

Auditory information travels from the cochlea in our ears deep into the brainstem eventually reaching the auditory cortex in the temporal lobe (Dykstra et al., 2017). As described by Moore (2012) a sound is created by vibrations that cause a change in pressure. The sound pressure wave travels through a transmission medium such as gas, liquid or solid to our ear. Here it travels through a subset of inner ear structures until reaching the cochlea where vibrations are converted into nerve impulses and sent to the cochlear nucleus in the brain stem. The information then travels through a series of structures in the brain stem (see figure 1.) where information is processed before being projected as auditory input to the thalamus (Nelken, Fishbach, Las, Ulanovsky, & Farkas, 2003). The processing properties of the auditory subcortical areas in general and inferior colliculus, in particular, change the complexity level of the information before it reaches the auditory cortex. This subcortical processing power is different from all other sensory systems (Moore, 2012). It has been suggested that the inferior colliculus processing level is equivalent to that of the primary visual area (V1; Nelken et al., 2003). In the last step of this complex process, the auditory information is projected from thalamus to the auditory cortex (Kral & Eggermont, 2007). The auditory cortex is located in the temporal lobe at parts of superior temporal gyrus, Heschl's gyrus and extending into the lateral fissure (Moore, 2012).

Kaas & Hackett (2000) suggests four stages of cortical processing for the auditory system. The first stage is conducted in the auditory cortex. In monkeys, this structure consists of three areas with primary like features which in turn constitutes the auditory core. The core consists of a caudal (A1), rostral (R), and a more rostral temporal field (RT). The fields in the auditory core form a topological map representing the frequency of tones like a ladder. Highest frequency tones are represented in the caudal end of A1 and from there falling gradually to the rostral end (RT) (Merzenich & Brugge, 1973; Steffen, Simonis, Thomas, Tillein, & Scheich, 1988). The core is surrounded by a tight belt composed from several fields where the second stage of processing occurs. A wider “parabelt” of separate areas performs the third level of processing. The parabelt connects to adjacent areas in the temporal lobe and more distant areas in the parietal and frontal lobe which constitutes the fourth stage of processing (Kaas & Hackett, 2000). Multiple research suggests that the organization of the human auditory system is similar to that of monkeys which has been the main source for scientific research in the auditory system

(Belin, Zatorre, Lafaille, Ahad, & Pike, 2000; Binder et al., 2000; Démonet et al., 1992; Howard et al., 2000; Kaas & Hackett, 1998).

The auditory cortex generates representations of auditory objects which can be assigned properties such as spatial location, source identity, and meaning by higher-order areas (Kral & Eggermont, 2007; Nelken et al., 2003). This organization is similar to the visual system where feedforward connections project simple information through the visual system and feed backward and horizontal connections integrate the information into percepts (Koivisto & Revonsuo, 2010; Lamme, 2010). Research of the auditory pathway has shown that cortical processes influence the plastic reorganization of subcortical structures. This divides the similarities between vision and audition while also strengthening the concept of bottom-up and top-down processes in hearing (Kral, Yusuf, & Land, 2017). Lamme (2010) suggests that the process resulting in auditory awareness should be similar to that same process in visual awareness. Kral & Eggermont (2007) provides evidence of feedforward and feed-backward processes in the auditory system of cats. Thus, suggesting that the same system could be present in man. This top-down effect could be produced by feed backward processes and horizontal connections giving further support for an awareness system similar to that of visual awareness.

Auditory research has revealed two dissociated information pathways (Clarke et al., 2002; Moore, 2012). A ventral sound identification ("What") and a dorsal sound localization ("Where") pathway (Alain, Arnott, Hevenor, Graham, & Grady, 2001; Hickok & Poeppel, 2004; Romanski et al., 1999). The what pathway handles perception and the where pathway handles action (Goodale & Milner, 1992). These networks are similar to the ventral ("what") and dorsal ("where") pathways in the visual system (Hubel & Wiesel, 2004). Thus, suggesting a similar organization for information processing in both senses (Alain et al., 2001). The ventral and dorsal pathways originate from the auditory cortex in superior temporal gyrus bilaterally and then projects to spatial and non-spatial domains of the frontal lobe, respectively (Romanski et al., 1999).

Feed-forward and Feed-backward Connections

When we perceive a visual scene, a rapid flow of information sweeps along the feedforward connections through our brain in what is called a feedforward sweep (FFS) of information processing (Lamme, 2010). In about 200 ms this process rapidly flows through V1 to extrastriate and areas involved in control and execution of movement. On its way through the hierarchy of the visual areas elemental information such as color, shape, orientation, and motion are integrated into our receptive field (Bullier, 2001; Lamme & Roelfsema, 2000). When FFS flows through a specific area the horizontal connections start to communicate to distant cells within that region (Salin & Bullier, 1995).

An important feature of the organization of the FFS is that there are many parallel FFSs that are traveling simultaneously at different speeds (Lamme & Roelfsema, 2000). This allows activation in higher-order areas of vision to bypass the hierarchical cortical structure. Some areas, for example, the frontal eye fields are activated almost as fast as V1 despite being higher up in the cortical order. This is contradictory to what might be expected considering the hierarchical structure of vision but the phenomena have several possible explanations (Lamme & Roelfsema, 2000). Firstly, the feedforward connections are not always connected to the closest possible neuron. This creates a system where hierarchy falters at the level of individual neurons. Secondly, the speed of FFS differs. This is because FFS consists of different types of information that travel along separate visual pathways. This is important since not all information leads to consciousness. Thirdly, there are multiple sources of visual information. Pulvinar and superior colliculus are two examples of subcortical areas that might bypass V1 and project directly to extrastriate areas (Nowak & Bullier, 1997).

There is an element of competition in the FFS processes (Lamme, 2010). Not all stimuli reach the top of the hierarchical structure and are faced out by attentional processes along the way. Desimone & Duncan (1995) suggests that attentional selection is responsible for resolving this competition. Therefore, attention can be considered to be the depth of processing for a stimulus (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2004).

Recurrent Processing

As soon as the FFS reaches an area in the brain it is followed by a feed backward sweep of information processing. This feed backward sweep reactivates previous structures in the hierarchy and causes recurrent loops of activation between higher and lower-order brain areas (Koivisto & Revonsuo, 2010; Lamme, 2004; Lamme, 2010). This communication between and within brain areas after the FFS is called recurrent processing and is suggested to correlate to VAN and LP (Lamme, 2004). Early recurrent loops (local recurrent processing) occur between and within lower areas while later recurrent loops (global recurrent processing) occur between sensory and higher-order areas such as the frontoparietal network (Eklund & Wiens, 2019;

Koivisto & Revonsuo, 2010; Victor A. F. Lamme & Roelfsema, 2000). The local recurrent processing occurs in the same interval as VAN and correlates to awareness of a stimulus. The global recurrent processing is correlated to the time interval of LP and enables access to and report of our the perceived stimulus (Eklund & Wiens, 2019; Lamme, 2010). Lamme & Roelfsema (2000) suggests that this recurrent processing leads to more complex cognitive and behavioral processes that constitute the basis of subjective awareness. Attentional competition can strengthen or weaken this process deciding if it will spread to global recurrent processing or not (Dehaene et al., 2006).

The Role of Consciousness in Recurrent Processing

Lamme (2010) and recurrent processing theory claims that there are two representations constituting consciousness. A large capacity representation that captures an almost perfect copy of the world that fades away in seconds called phenomenal consciousness, and a stable representation containing less information but allowing for access and report called access consciousness. Access consciousness is linked to working memory and attention while phenomenal consciousness is linked to the pure subjectiveness of an experience. Phenomenal consciousness is conceptually separate from the limited capacity network that only represents chosen parts of the phenomenal information. The recurrent processing theory claims that phenomenal consciousness, electrophysiologically represented by VAN and AAN, correlates to awareness. Further, the theory claims that access consciousness, electrophysiologically represented by LP, constitutes post-conscious mechanisms. Access consciousness thus only consists of post-conscious mechanisms that get access to already present phenomenal information while phenomenal consciousness constitutes the basis for awareness.

Baars (2005) presents the global workspace theory and its view on consciousness: “It is broadly true that what we are conscious of, we can report with accuracy.” (p. 45). Thus, consciousness is defined by the subjective report of its presence. Global workspace theory suggests a fleeting system of conscious perception that causes widespread activation in the brain enabling access between functions that are otherwise separate (Baars (2005). The theory can be philosophically described as a theater of mental functioning where the center stage is lit up by a spotlight representing our present conscious perception. The darkness outside the spotlight of attention is filled with actors and technicians representing working memory and other unconscious processes that enable future conscious percepts. In other words, there is no consciousness beyond the spotlight of attention (access consciousness).

Recurrent processing theory and global workspace theory both agree that recurrent processing enables consciousness(Dehaene & Naccache, 2001; V. A. Lamme, 2006). Lamme & Roelfsema (2000) argue that recurrent processing between lower and higher order sensory areas is sufficient to enable conscious processing. This is known as early or local recurrent processing. Therefore, conscious experiences are dissociated from cognitive mechanisms such as attention, memory and perceptual report that arises later in global recurrent processing (Dykstra et al., 2017). If local recurrent processing enables consciousness it entails the counterintuitive view that some phenomenological states that are inaccessible and unreportable (Lamme & Roelfsema, 2000). In other words, it is something that it feels like to have sensory experiences even if they can't be reported. The global workspace theory claims that in order for sensory information to reach consciousness it has to be processed by cognitive mechanisms such as attention and working memory. Thus, consciousness is enabled as it activates a global neuronal network of recurrent processing between sensory areas and frontoparietal cortex (Baars, 2002; Dykstra et al., 2017). Consequently, sensory experiences that cannot be accessed or reported should not be regarded as conscious in any way.

Local and global recurrent processing can be measured and compared in relation to awareness through VAN, AAN, and LP (Eklund & Wiens, 2019; Koivisto & Revonsuo, 2010; Lamme, 2004). According to Lamme (2010), VAN and AAN should correlate with early recurrent processing that enables the phenomenal experience. Parts of this experience win the competition for attention and are thus processed by cognitive mechanisms represented by LP that makes it accessible (Dehaene & Naccache, 2001). The winning stimuli of this attentional competition spark global recurrent processing between sensory areas and frontal cortex which according to Baars (2005) and global workspace theory enable conscious perception. This activity can be measured in the P3 interval as LP (Salti et al., 2012).

The No-response Paradigm and Unrelated Mechanisms of Consciousness

Block (2007) asks: "does what it is like to have an experience include whatever cognitive processes underlie our ability to report the experience?" (p. 483). In the current experiment, we investigate the possibility that the P3 ERP called LP in the auditory system has been exaggerated due to the method used to report awareness to a stimulus. If this is the case, it could be argued that post-conscious mechanisms have been included in the P3 measurement in the past. By finding and comparing both auditory ERPs (AAN and LP) using a no-response paradigm we aim to dissociate consciousness related mechanisms from pre- and post-conscious mechanisms.

It might seem necessary to require subjective reports when studying the NCC. But contrary to this belief, the extensive reliance of report in the past might have caused a bias to include unrelated cognitive mechanisms in NCC measurements (Tsuchiya et al., 2015). In the current study, we will use a no-response paradigm to avoid the inclusion of unrelated mechanisms in our measurements.

A conventional method for investigating awareness is holding a stimulus constant and measure how consciousness fluctuates to that stimulus (Dykstra et al., 2017). For example, in the present experiment, a tone is calibrated to a level where it is heard 50% of the time. The consciousness fluctuates, creating aware and unaware conditions that can be compared. However, recent evidence shows, that a comparison between two distinct reports confounds the results by including unrelated cognitive mechanisms (Aru et al., 2012). Although there are ways to counter such confounds (Aru et al., 2012) a no-response paradigm can be used to avoid them altogether. But how is it possible to measure consciousness without report?

There are several ways to measure consciousness without report (Tsuchiya et al., 2015). In recent years some progress has been made in communicating with unresponsive patients using brain-computer interfaces (Naci et al., 2012). Another example is using physiological measures such as changes in pupil size to infer awareness (Frässle, Sommer, Jansen, Naber, & Einhäuser, 2014). The present experiment uses a no-response task based on an experiment by Koivisto et al. (2016). They conducted an electrophysiological experiment with the aim of dissociating post-perceptual processes ERPs in visual awareness. They found VAN and LP and compared them using a GO-NOGO task. A GO-NOGO task is a no-response paradigm with two opposite conditions. A GO condition, where participants report the presence of a stimulus by pressing a button and the absence of a stimulus by not answering at all, and a NOGO condition where participants report the presence of a stimulus by not answering and the absence of a stimulus by pressing a button. An ERP was found at the N200 amplitude (VAN) for a negative activation in the aware GO and aware NOGO condition that was absent in the unaware conditions. VAN was followed by a positive spike in the P3 amplitude (LP) in both aware conditions that was enhanced in the aware-GO condition compared to the aware-NOGO condition. They suggest that the difference in LP activation reflects post-perceptual processes caused by the report. The findings from this study have yet to be discovered in audition. In the present experiment, we transition from vision to audition using a similar setup. We hope to find the previously reported ERPs in audition (AAN and LP) and investigate if they are affected by the response.

Method

Subjects

The study contained 18 participants (mean age = 29, range: 21-38, seven males). They were recruited from the local university (Stockholm University) and from online billboards. To participate in the study subjects were required to have normal or close to normal hearing and vision, and not have any history of neurological disorders. These requirements were self-assessed by the participants. All subjects signed a written consent in accordance with the principles of the regional ethics board and received a gift voucher of 100 Swedish crowns.

Stimuli

A sinusoidal 100-ms tone (f = 1000 Hz) with 5-ms fade. The tone was presented to both ears through in-ear tube phones (ER2; Etymotic Research Inc., IL; www.etymotic.com). They are outfitted with earplugs to reduce noise. The tone was generated by PsychoPy v 3 (Peirce, 2007). It was presented in a small silent room without ambient background noises.

Procedure

Subjects perform a sound detection task while seated in front of a computer screen with their chin in a chinrest. The task consists of 600 trials (480 critical, 60 control, and 60 catch). Critical trials contain a tone at the individual auditory awareness threshold (see below), control trials contain a tone at 10 dB above the individual awareness threshold and catch trials that do not contain a tone.

The trials are divided into six blocks. Each block consists of 100 trials (80 critical, 10 control, and 10 catch). Between each block, participants were given a short break. For each subject and block, the order of critical, control, and catch trials is randomized within each set of 10 trials (8 critical, 1 control, and 1 catch). On each trial, a black fixation cross is shown for 500 ms. In critical trials, a tone is played 500 ms after trial onset (at the offset of the fixation cross). After the offset of the fixation cross, subjects have three seconds to respond whether or not they heard a soft tone.

The blocks were divided into two conditions: a *respond-if-aware* and a *respond-if-unaware* block. Before each block, subjects receive one of two instructions. In the *respond-if-aware* condition, they are instructed to press the spacebar if they heard a soft tone and not to press the spacebar if they did not hear a soft tone. In the *respond-if-unaware* condition, they are instructed to press the spacebar if they did not hear a soft tone and not to press the spacebar if they did hear a soft tone. The instructions alternate over blocks and the starting condition alternates between subjects.

Before the experiment began, subjects practiced the task by listening for a tone after the fixation cross disappears. This short practice session is identical to the main task but with clearly audible tones. After the practice session, interleaved staircases are used to calibrate the tone to a level that each individual subject reports as aware on approximately 50% of the trials (individual auditory awareness threshold). The staircase procedure consists of three interleaved staircases (trials are presented in random order). One staircase starts at 4 *dB*. The other two staircases start at 20 dB above and below. The staircase procedure is as follows: If the subject reports hearing a tone, the level decreases. If the subject reports not hearing a tone, the level increases. For each staircase, reversal steps are 8, 8, 4, 4, 2, and 2 for the first six reversals, and 1 dB for the subsequent reversals. Every separate staircase stops after 12 reversals.

After the calibration, a validation block is run with 50 critical trials. The level of the critical tone in the validation procedure is determined from both the convergence of the three staircases (from visual inspection) and a psychometric response function. If the subject is not close to 50% of tones rated as aware, the tone level is adjusted by using a psychometric response function that estimates their threshold. Validations are repeated until we are satisfied that we have a good approximation of their awareness threshold. If the aware criterion from validations continuously deviates from the 50% threshold, new calibrations are run. If the threshold is not found after five blocks of calibration/validation, the subject is tested at a level that seems most promising in capturing the individual auditory awareness threshold.

EEG recording

EEG data are recorded from 64 electrodes at standard 10/20 positions and two additional electrodes (tip of the nose, and one on the right zygomatic bone) with an Active Two BioSemi system (BioSemi, Amsterdam, Netherlands). The 64 standard 10/20 positions are recorded with pin electrodes in a 64-electrode EEG cap (BioSemi headcap). The tip of the nose and the cheek are recorded with flat electrodes attached with adhesive disks. The cheek electrode is used to discover eye-blink components in cases where these components occur at the same time as the early or late time intervals. If they occur in those intervals they are filtered from the rest of the activity in order to avoid constraneous activity. The Two additional, system-specific positions are recorded with pin electrodes in the EEG cap. The CMS (between PO3 and POz) serves as the internal reference electrode and the DRL (between POz and PO4) as the ground electrode. Data are sampled at 1024 Hz and altered with a hardware low-pass filter at 104 Hz, and a software high-pass filter at 1 Hz.

EEG analysis

Individual EEG electrodes are visually inspected to detect noisy electrodes in ActiView. Any noisy electrodes are interpolated (spherical spline interpolation) from neighboring electrodes. However, if more than two noisy electrodes are neighbors or the total number of noisy electrodes exceeds five, the subject is excluded. Eye-blinks is corrected with ICA.

For all trials, epochs are extracted from 100 ms before tone onset to 600 ms after. Electrodes are referenced to the tip of the nose. Each epoch is baseline corrected with the mean of the 100-ms interval before tone onset. For each participant, amplitude ranges (i.e., max minus min) within individual epochs are extracted, and the distribution of these is visually inspected to exclude apparent outliers. Cutoffs are adjusted individually to retain as many trials as possible while reducing the potential effects of outliers. Inspection is blind to the type (critical, control, or catch) and awareness rating of individual trials to avoid bias.

Four ERPs are calculated from the critical trials:

1. *The aware response ERP* is the mean ERP to tones that are rated as aware (by pressing spacebar) in the *respond-if-aware* condition.
2. *The unaware response ERP* is the mean ERP to tones that are rated as unaware (by pressing spacebar) in the *respond-if-unaware* condition.
3. *The aware no-response ERP* is the mean ERP to tones that are rated as aware (by not pressing spacebar) in the *respond-if-unaware* condition.
4. *The unaware no-response ERP* is the mean ERP to tones that are rated as unaware (by not pressing spacebar) in the *respond-if-aware* condition.

In order to find the ERPs two intervals were investigated based on earlier research findings (Eklund & Wiens, 2019). For the early interval (H1), mean amplitudes are calculated across 15 electrodes (C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, and P4) in the interval between 160 and 260 ms after tone onset. For the late interval (H2), mean amplitudes are calculated across 15 electrodes (C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, and P4) in the interval between 350 and 550 ms after tone onset (See figure 2).

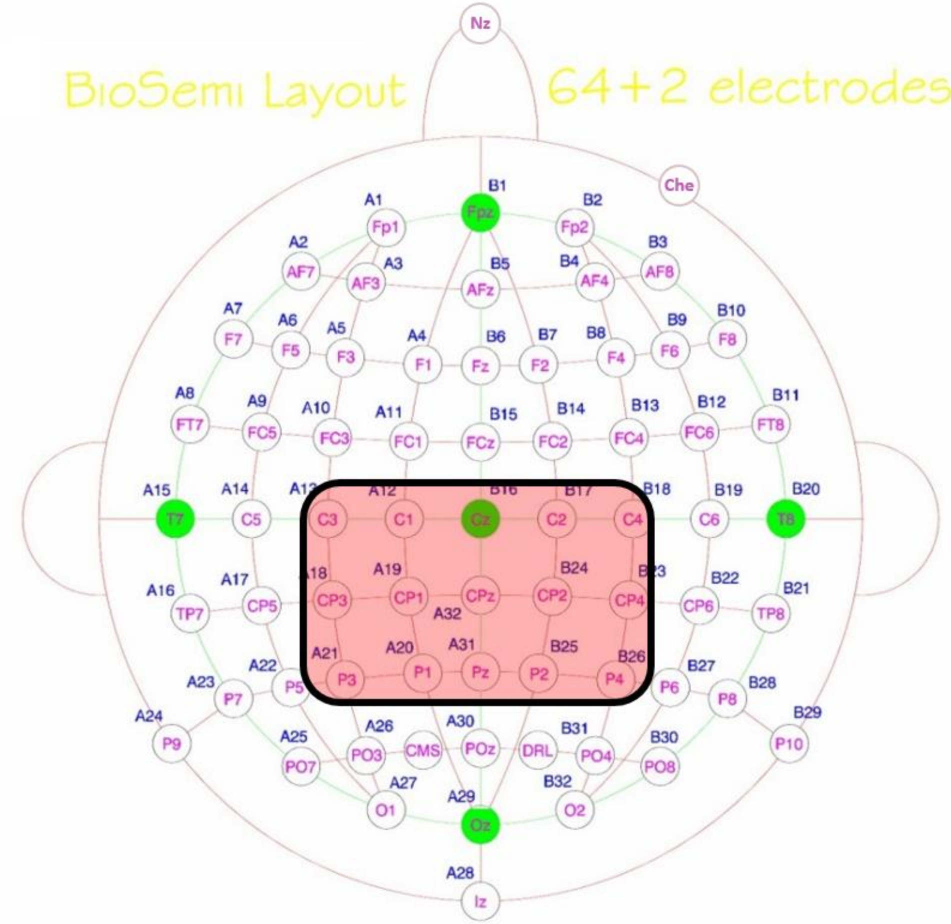

Figure 2. Electrode layout for the experiment. The mean amplitudes are calculated across the 15 electrodes in the highlighted area.

Statistical Analysis

The study consists of two main hypotheses:

1. For the early interval, we predict an amplitude difference for aware trials minus unaware trials. This negativity does not differ between the response ERP and the no-response ERP. This negativity is observed for the response ERP. This negativity is observed for the no-response ERP.
2. For the late interval, we predict a positive amplitude difference for aware trials minus unaware trials. This positivity is larger for the response ERP than the no-

response ERP. This positivity is observed for the response ERP. This positivity is observed for the no-response ERP.

The mean amplitudes in N200 (160-260 *ms*) and P3 (350-550 *ms*) for critical trials in both conditions were statistically analyzed with paired sample T-tests (Statistik: p-value, confidence interval).

The presence of AAN is investigated by comparing the difference in ERP activation between aware and unaware responses in both conditions: the aware response ERP minus the unaware response ERP, and the aware no-response ERP minus the unaware no-response ERP. This analysis computes a negative amplitude in the N200 interval (160-260 *ms*) correlating to auditory awareness (AAN) for the *respond-if-aware* and *respond-if-unaware* condition.

The presence of LP is investigated by comparing the difference in ERP activation between aware and unaware responses in both conditions: the aware response ERP minus the unaware response ERP, and the aware no-response ERP minus the unaware no-response ERP. This analysis computes a positive amplitude in the P3 interval (350-550 *ms*) correlating to auditory awareness (LP) for the *respond-if-aware* and *respond-if-unaware* condition.

AAN and LP are then compared to investigate if they differ in activation between conditions: the aware response AAN minus the aware no-response AAN in the N200 interval (160-260 *ms*), and the aware no-response LP minus the aware no-response LP in the P3 interval (350-550 *ms*).

Results

Behavioral Data

Table 1
Descriptive and inferential statistics for the mean amplitude differences of aware - unaware trials.

ERP	N	Mean (*μV*)	SD	CI−	CI+
AAN response	18	−1.46	1.19	−2.05	−0.87
AAN no-response	18	−1.14	1.31	−1.80	−0.49
LP response	18	0.33	0.92	−0.13	0.79
LP no-response	18	1.00	1.15	0.43	1.57
AAN response minus no-response	18	−0.32	1.65	−1.14	0.50
LP response minus no-response	18	−0.67	1.49	−1.41	0.07

Note. CI stands for the confidence interval (95%). Mean µV describe the average micro voltage amplitude of trials used to compute the event-related potential (ERP).

Table 2
Descriptive statistics of behavior data.

Responses	Mean	SD
Critical: Aware response (%)	42.13	12.48
Critical: Unaware response (%)	51.27	10.71
Critical: Aware non-response (%)	48.73	10.71
Critical: Unaware non-response (%)	57.87	12.48
Control: Hits response (%)	97.59	5.34
Control: Hits non-response (%)	96.85	5.99
Catch: False alarms response (%)	5.37	5.73
Catch: False alarms non-response (%)	7.41	8.21
Reaction Time: Aware response (*ms*)	694	12.53
Reaction Time: Unaware response (*ms*)	811	14.14

Note. The data shown in this table indicate that participants succeed in following task instructions. The tones at the threshold were close to optimal (50%) and they rated only a few tones as aware when there was no tone (i.e., catch trials).

Table 1 shows reaction times and errors conducted by the participants. They withheld or responded adequately according to instructions and there were no significant differences between trials in both conditions. The descriptive statistics of the experiment is provided in table 2.

Event-related Potentials of Auditory Awareness: Critical Trials

Table 1 shows the descriptive and inferential statistics for the mean amplitudes, figure 3 and 4 shows the mean amplitudes for the ERPs in both conditions.

Auditory Awareness Negativity

To establish the presence of AAN we hypothesized a negative amplitude difference in the early interval (160-260 ms) between aware and unaware trials in both conditions. This was tested with paired sample T-tests.

On average, the aware response ERP showed a stronger negative amplitude (*M* = -1.72, *SD* = 1.67) than the unaware response ERP (*M* = -0.30, *SD* = 1.24). This difference, -1.43, 95% *CI* [-2.05, -0.86], was significant $t(17) = -5.17$, $p < .001$. In other words AAN was observed in the response condition.

On average, the aware no-response ERP showed a stronger negative amplitude (*M* = -1.98, *SD* = 0.82) than the unaware no-response ERP (*M* = -0.82, *SD* = 1.68). This difference, -1.14, 95% *CI* [-1.80, -0.49], was significant $t(17) = -3.63$, $p = .002$. In other words AAN was observed in the no-response condition. Descriptive and inferential statistics for the mean amplitude differences of aware - unaware trials.

Further, we hypothesized that this negativity will not differ between the response ERP and the no-response ERP. This was tested with a paired samples T-test. On average, AAN in the response condition (*M* = -1.46, *SD* = 1.19), did not differ from AAN in the no-response condition (*M* = -1.14, *SD* = 1.31). This difference, −1.25, 95% *CI* [-1.14, 0.50], was not significant $t(17) = -0.66$, $p = .512$. Thus, type of response condition did not affect AAN.

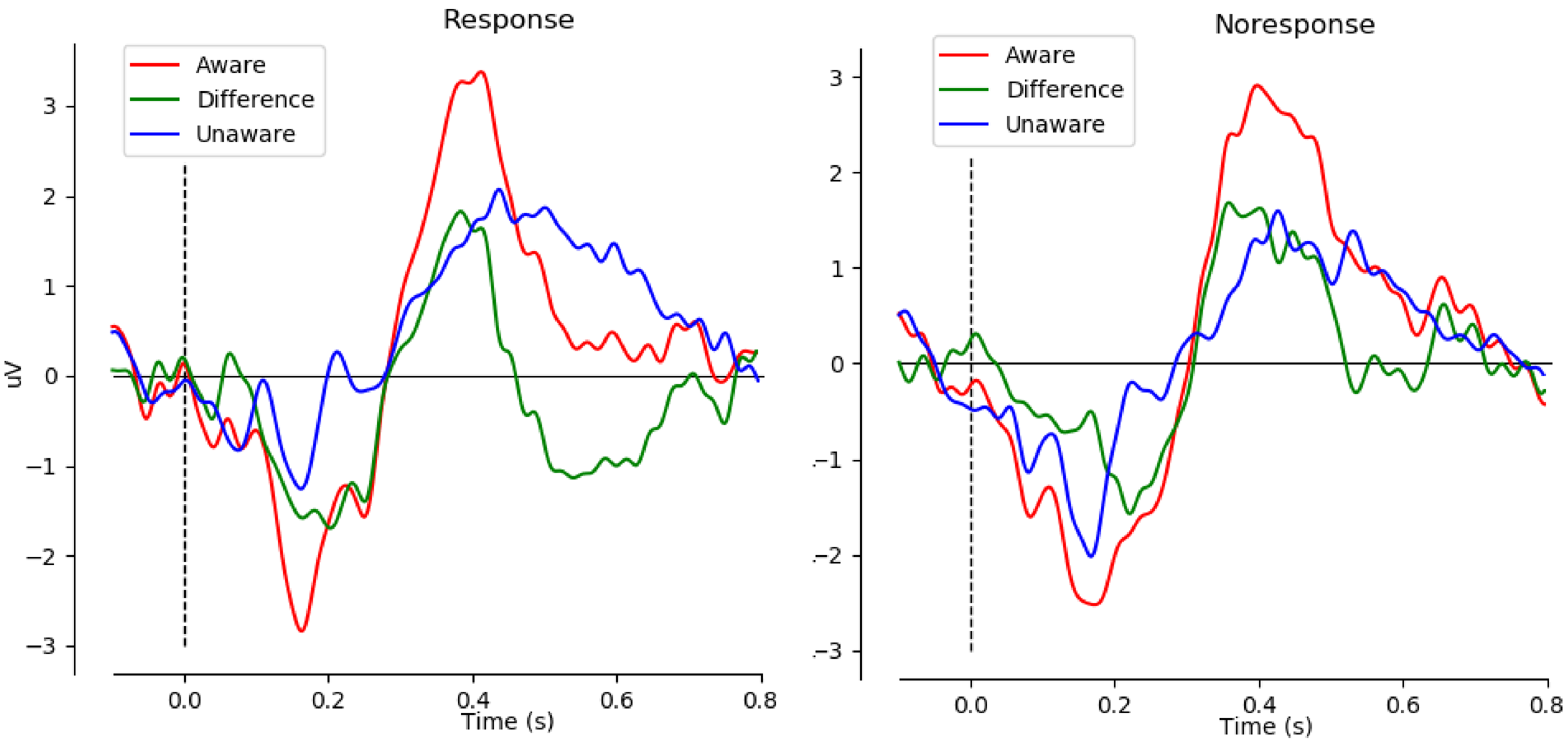

Figure 3. Grand mean amplitude for both conditions (n=18). Aware trials (red), unaware trials (blue), and aware minus unaware trials (green).

Late Positivity

To establish the presence of LP we hypothesized a positive amplitude difference in the late interval (350-550 *ms*) between aware and unaware responses in both conditions. This was tested with paired sample T-tests.

On average, the aware response ERP showed a stronger positive amplitude (*M* = 1.98, *SD* = 1.12) than the unaware response ERP (*M* = 1.62, *SD* = 1.07). This difference, 0.36, 95% *CI* [-0.13, 0.79], was not significant *t*(17) = 1.69, *p* = .114. In other words LP was not observed.

On average, the aware no-response ERP showed a stronger positive amplitude (*M* = 2.15, *SD* = 1.34) than the unaware no-response ERP (*M* = 1.17, *SD* = 0.81). This difference, 0.98, 95% *CI* [0.43, 1.57], was significant *t*(17) = 3.48, *p* = .003. In other words, *LP* was observed.

Further, we hypothesized that this positivity is larger for *LP* in the response condition than the no-response condition. This was tested with a paired samples T-test. On average, weaker positive amplitudes were measured for *LP* in the response condition (*M* = 0.33, *SD* = 0.92), than in the no-response condition (*M* = 1.00, *SD* = 1.15). This difference, -0.66, 95% *CI* [-1.41, 0.07], was not significant *t*(17) = -1.71, *p* = .106 In other words, the type of response did not affect LP

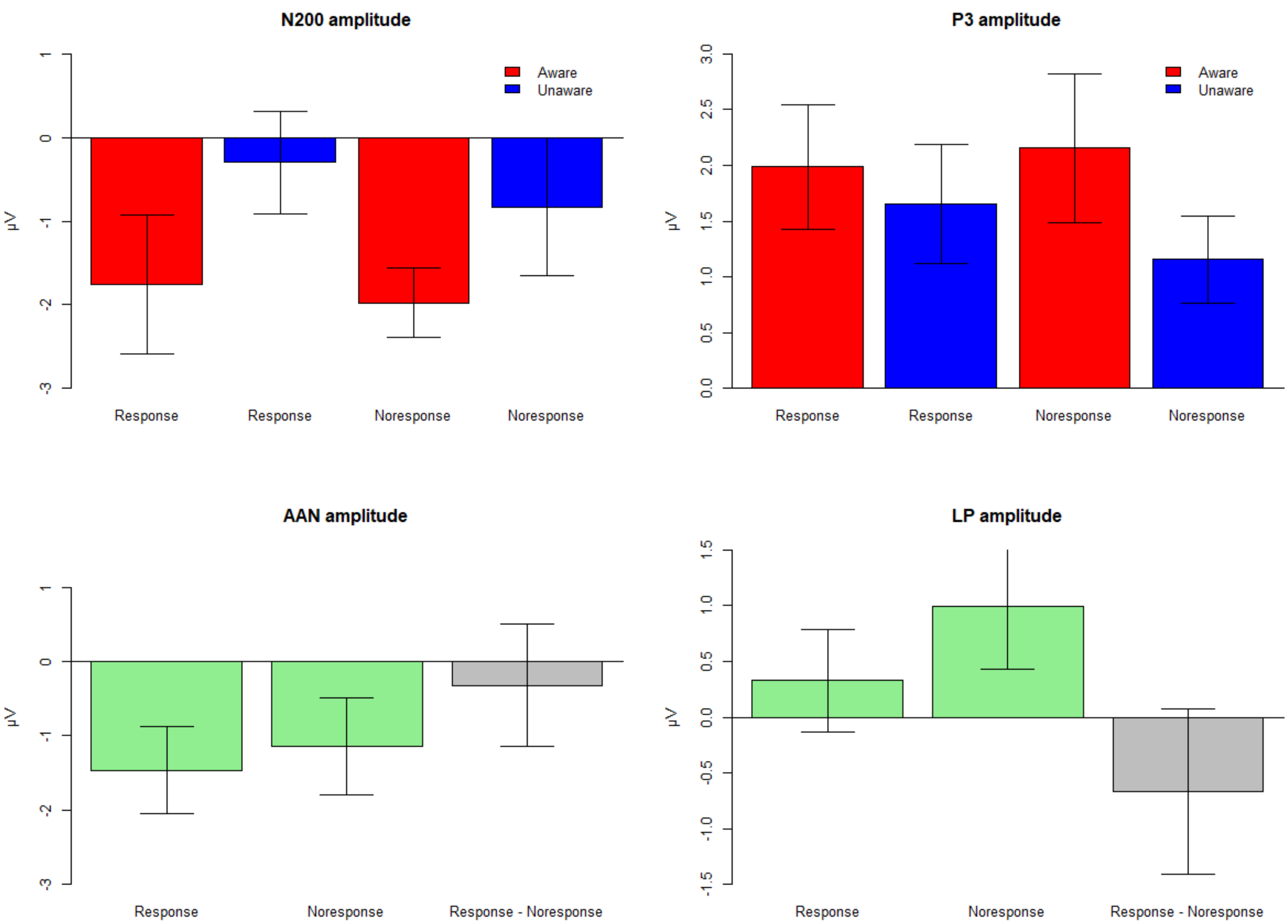

Figure 4. The staple diagrams show the mean amplitudes and standard deviation for measured event-related potentials divided into their conditions (response, no-response). The top charts show the mean amplitudes for aware (red) and unaware (blue) trials in the N200 (left) and P3 (right) interval. The bottom charts show the mean amplitude for AAN (auditory awareness negativity) to the left and LP (late positivity) to the right, conditions represented by the green columns and the difference between conditions is represented by the grey column.

Discussion

The presence of a negative amplitude (AAN) for the early interval (160-260 *ms*) was found in both conditions. It was observed in the response and the no-response condition and did not differ between them. Thus, fulfilling the first main hypothesis of the study. The positive amplitude (LP) in the late interval (350-550) could be found in the no-response condition but not in the response condition contrary to the hypothesis. Further, it did not differ in amplitude between conditions.

The behavioral results show that response requirement did not affect awareness. The percentage of participants aware or unaware of all types of trials (critical, catch, and control) were equal between conditions. Thus, the data supports the idea that the response requirement does not affect the subject's perception of the stimuli. Further, false alarms rates (responding aware of when there was no tone) in both trials was low (mean = 6,39 %). This means that participants followed instructions well but compared to Koivisto et al. (2016) who only had 1,6 % false alarms our frequency is rather high. This could be from differences in instructions or due to the fact that we conducted our tests in different sensory modalities.

VAN is suggested to be the earliest correlate of awareness by recurrent processing theory (Lamme, 2010) and has been extensively studied in visual awareness research (Koivisto & Revonsuo, 2010). Only sparse evidence exists that similar processes might occur in audition (Eklund & Wiens, 2019; Hillyard et al., 1971; Parasuraman & Beatty, 1980). Our findings of AAN in both conditions support early awareness processes role in consciousness by providing evidence for corresponding activity in a different sensory modality. Further, this result is in line with the recurrent processing theory's prediction of an early awareness related activity following a stimulus (Lamme, 2010).

Salti et al. (2012) conducted an experiment investigating the role of P3 in visual awareness. The study reached the conclusion that P3 correlated to awareness but found no evidence of VAN. They suggested that VAN is related to other cognitive processes preceding awareness and not to awareness itself. Further, they stated that VAN should be larger when seen and unseen stimuli differ substantially compared to tasks where the stimulus generate only small processing differences (not clearly seen stimuli). Our experiment uses a threshold based stimulus that is hard to detect, thus measuring small processing differences in the brain. This contradicts

Salti et al. (2012) and suggests that early recurrent processing plays a role in awareness in audition.

Evidence for LP in the no-response condition was found as hypothesized. We did, however, not find a significant LP in the response condition. This does not support our hypothesis and stands in contrast to the findings by Koivisto et al. (2016). They found that LP in the response condition was significantly larger than in the no-response condition. This is in line with their previous review (Koivisto & Revonsuo, 2010). However, our results show a strong but brief ERP early in the late interval (350-550 *ms*) of the response condition (see figure 3). Thus, it is possible that the configuration of our task reduced the duration of the P3 amplitude. For example, our fixation cross is directly followed by a stimulus which might make participants more prepared for the upcoming stimulus. This could decrease their reaction to the stimulus and thus change the formation of the activation. Our low amount of participants might also have skewed the results. Previous awareness studies have found the P3 activation in the response condition (Dykstra et al., 2017; Eklund & Wiens, 2019, 2019; Koivisto & Revonsuo, 2010; Koivisto et al., 2016; Lamme, 2010; Salti et al., 2012). Therefore, I suspect that the interval chosen to measure LP missed its significance. Further experiments should replicate the study to see if the LP activation remains short but strong in the response condition.

The second part of the experiment aimed to separate post-perceptual processes from AAN and LP. This was done successfully in Koivisto et al. (2016) and builds on the no-response paradigm (Tsuchiya et al., 2015). Using a no-response paradigm separates post-perceptual processes from consciousness by eliminating the differences in activity between active and passive response conditions. For the early interval, we showed that response condition had no effect on AAN. There were no differences in amplitude between conditions. This is in line with recurrent processing theory (Lamme & Roelfsema, 2000) which argues that local recurrent process is necessary and sufficient for phenomenal consciousness. The quantity of information being processed in early recurrent processing is vast and only parts of it ever reach access consciousness. Most information remains in the periphery of conscious experience. Lamme (2010) claimed that this vast information processing constitutes phenomenal consciousness and that access to this information is mediated by post-perceptual mechanisms. Thus, recurrent processing is necessary before stimuli can enter consciousness. Early recurrent processing starts appearing after 100 ms and is thought to be measured by AAN and VAN (Eklund & Wiens, 2019). The fact that AAN activation did not change between conditions suggests that AAN is free from unrelated cognitive mechanisms. If the opposite were true, the no-response paradigm being implemented should have produced different results. Hence, our findings support the recurrent processings suggestion of early recurrent processings role in awareness. If we could provide evidence for the separation of post-perceptual processes in LP this would provide further evidence for early recurrent processing role in consciousness and discredit theories that claim early recurrent processing to be related to pre-conscious mechanisms (Salti et al., 2012).

The comparison of LP in both conditions did not amount to a significant result. Although LP was found in the no-response condition, P3 activation in the response condition was observed and the confidence interval was large. This means the effect had much variability. The activation peaked early and faded too quickly to be perfectly captured by our wide interval (350-550 *ms*) analysis. Thus, a too wide interval might have been chosen to analyze LP. This fact influences our statistical analysis and probably produced a type II error. In other words, we might have missed LP due to our choice of statistical analysis.

Looking at the graph over the no-response condition reveals an unexpected result. Around 100 ms a clear ERP with negative amplitude can be seen (Figure 3). It is unclear why such activation would be present in the no-response condition and missing in the response condition. The activation is not seen in vision and could thus be related to the auditory system. Since the structure of the auditory system is different from vision with more areas processing the stimuli information before reaching the cortex, it should be possible for unknown processes related to consciousness to appear. Are these processes enabled by local recurrent processing? If so, there might be an earlier ERP related to consciousness in audition. This is unlikely due to the early onset of the activation and the fact that the ERP was only discovered in the no-response condition. The activation could also correlate to pre-conscious processes unique to the auditory system. Another possibility is that the counterintuitiveness of the no-response paradigm (not reporting a perceived stimulus) might have produced an inhibition activity in subjects when they hindered themselves from answering. Either way, it remains a fascinating unexpected result that should be investigated more closely in further studies.

In coma-related disorders of consciousness, most diagnoses are done by behavioral assessment. Research has shown that the rate of misdiagnosis of these patients can be as high as 43 % of cases (Schnakers et al., 2009). The term coma-related disorders usually include vegetative state (patient has sleep/wake cycles, is unaware of surroundings and has very limited brain function), minimally conscious state (patient has sleep/wake cycles and shows inconsistent signs of responsiveness), and locked in syndrome (patients are aware but show no signs of responsiveness, sometimes they are able to perform simple eye movements; Laureys, Owen, & Schiff, 2004). There are limited methods of assessing consciousness by brain imaging, but it requires special equipment and is expensive (Guldenmund, Stender, Heine, & Laureys, 2012). In locked-in patients, time of diagnosis is correlated with the rate of recovery which makes an easy method of diagnosing these patients pivotal (Laureys et al., 2005). If AAN could reliably be defined as a correlate of consciousness and a true no-response task were devised an argument could be made that this technique could be used to help diagnose patients with coma related disorders that retain a functioning auditory system.

Conclusion

The most important finding of this study is AAN and showing that it can be separated from post-perceptual processes. This strengthens the recurrent processing theory and the view that pure subjective experience is possible without access and report. Although no significant differences could be found between LP in the response conditions, a strong activation could be seen but it was too brief to be significant in our chosen time interval of analysis. This might have caused a type II error that also leads to a statistically nonsignificant difference when comparing LP between conditions. Further research should be conducted to investigate the LP activation that could be seen but not significantly analyzed to see if this was a random effect of our study or if the method of analysis created a type II error. More research is needed in auditory awareness research in general and the no-response paradigm, in particular, to draw stronger conclusions about LP's role in consciousness. It is unclear if LP is a correlate of awareness as suggested by Dehaene et al. (2006) or if it is a correlate of post-perceptual processes as suggested by others (Andersen, Pedersen, Sandberg, & Overgaard, 2016; Koivisto et al., 2016). Another possibility is that LP includes both correlates of awareness and correlates of post-perceptual processes.

In the opening paragraph of the introduction, I pose the question: Is consciousness the pure experience of what it is like to be conscious, or is it the reasoning about and reporting of our experiences? This question is as fascinating as it is deceptive because there might not be a way to define consciousness. For example, where does pure phenomenology start and when does it become a holistic conscious percept? What kind of features are attached to it when it is bound to time and space? No research seems to find a clear jump between pure phenomenology to a fully recognized conscious percept. As Laureys et al. (2004) puts it: “consciousness is not an all-or-none phenomenon.” (p 3) which makes it hard to define. A hard definition would, of course, be favorable for the reductive nature of science but we should be open to the possibility that consciousness simply cannot be defined. The search for a hard definition of consciousness might be abandoned in favor of several models of explanation describing separate parts of what was once considered to belong to the term be consciousness. Thus, the conflict of what consciousness is and when it arises in the brain between the recurrent processing theory and the global workspace theory might just reflect upon the impossible task of defining an undefinable concept.

References

Alain, C., Arnott, S. R., Hevenor, S., Graham, S., & Grady, C. L. (2001). “What” and “where” in the human auditory system. *Proceedings of the National Academy of Sciences*, *98*(21), 12301–12306. https://doi.org/10.1073/pnas.211209098

Andersen, L. M., Pedersen, M. N., Sandberg, K., & Overgaard, M. (2016). Occipital MEG Activity in the Early Time Range (<300 ms) Predicts Graded Changes in Perceptual Consciousness. *Cerebral Cortex, 26*(6), 2677–2688. https://doi.org/10.1093/cercor/bhv108

Aru, J., Bachmann, T., Singer, W., & Melloni, L. (2012). Distilling the neural correlates of consciousness. *Neuroscience & Biobehavioral Reviews, 36*(2), 737–746. https://doi.org/10.1016/j.neubiorev.2011.12.003

Baars, B. J. (2002). The conscious access hypothesis: origins and recent evidence. *Trends in Cognitive Sciences*, *6*(1), 47–52. https://doi.org/10.1016/S1364-6613(00)01819-2

Baars, B. J. (2005). Global workspace theory of consciousness: toward a cognitive neuroscience of human experience. *Progress in Brain Research*, *150*, 45–53.

Babiloni, C., Vecchio, F., Miriello, M., Romani, G. L., & Rossini, P. M. (2005). Visuo-spatial consciousness and parieto-occipital areas: a high-resolution EEG study. *Cerebral Cortex*, *16*(1), 37–46.

Beck, D. M., Rees, G., Frith, C. D., & Lavie, N. (2001). Neural correlates of change detection and change blindness. *Nature Neuroscience*, *4*(6), 645. https://doi.org/10.1038/88477

Belin, P., Zatorre, R. J., Lafaille, P., Ahad, P., & Pike, B. (2000). Voice-selective areas in human auditory cortex. *Nature*, *403*(6767), 309–312. https://doi.org/10.1038/35002078

Bennett, M. R., Hacker, P. M. S., & Bennett, M. R. (2003). *Philosophical foundations of neuroscience* (Vol. 79). Blackwell Oxford.

Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *Archiv für Psychiatrie und*

Nervenkrankheiten, *87*(1), 527–570. https://doi.org/10.1007/BF01797193

Binder, J. R., Frost, J. A., Hammeke, T. A., Bellgowan, P. S., Springer, J. A., Kaufman, J. N., & Possing, E. T. (2000). Human temporal lobe activation by speech and nonspeech sounds. *Cerebral Cortex (New York, N.Y.: 1991)*, *10*(5), 512–528.

Blackmore, S. J. (2003). *Consciousness: An Introduction*. Oxford University Press.

Block, N. (1995). On a confusion about a function of consciousness. *Behavioral and Brain Sciences*, *18*(2), 227–247. https://doi.org/10.1017/S0140525X00038188

Block, N. (2005). Two neural correlates of consciousness. *Trends in Cognitive Sciences*, *9*(2), 46–52. https://doi.org/10.1016/j.tics.2004.12.006

Block, N. (2007). Consciousness, accessibility, and the mesh between psychology and neuroscience. *Behavioral and Brain Sciences*, *30*(5–6). https://doi.org/10.1017/S0140525X07002786

Bullier, J. (2001). Integrated model of visual processing. *Brain Research Reviews*, *36*(2), 96–107. https://doi.org/10.1016/S0165-0173(01)00085-6

Chalmers, D. J. (1996). *The conscious mind: In search of a fundamental theory*. Oxford university press.

Clarke, S., Bellmann Thiran, A., Maeder, P., Adriani, M., Vernet, O., Regli, L., … Thiran, J.-P. (2002). What and Where in human audition: selective deficits following focal hemispheric lesions. *Experimental Brain Research*, *147*(1), 8–15. https://doi.org/10.1007/s00221-002-1203-9

Crick, F., & Koch, C. (1990). Towards a neurobiological theory of consciousness. *Seminars in the Neurosciences*, *2*, 263–275.

Dehaene, S. (2014). *Consciousness and the brain: Deciphering how the brain codes our* *thoughts*. Penguin.

Dehaene, S., Changeux, J.-P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in Cognitive Sciences*, *10*(5), 204–211. https://doi.org/10.1016/j.tics.2006.03.007

Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. *Cognition*, *79*(1), 1–37. https://doi.org/10.1016/S0010-0277(00)00123-2

Démonet, J. F., Chollet, F., Ramsay, S., Cardebat, D., Nespoulous, J. L., Wise, R., … Frackowiak, R. (1992). The anatomy of phonological and semantic processing in normal subjects. *Brain: A Journal of Neurology*, *115 (Pt 6)*, 1753–1768.

Descartes, R. (1984). *The philosophical writings of Descartes* (Vol. 2). Cambridge University Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193–222.

Dykstra, A. R., Cariani, P. A., & Gutschalk, A. (2017). A roadmap for the study of conscious audition and its neural basis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1714), 20160103.

Eklund, R., & Wiens, S. (2018). Visual awareness negativity is an early neural correlate of awareness: A preregistered study with two Gabor sizes. *Cognitive, Affective, & Behavioral Neuroscience*, *18*(1), 176–188. https://doi.org/10.3758/s13415-018-0562-z

Eklund, R., & Wiens, S. (2019). Auditory awareness negativity is an electrophysiological correlate of awareness in an auditory threshold task. *Consciousness and Cognition*, *71*, 70–78. https://doi.org/10.1016/j.concog.2019.03.008

Frässle, S., Sommer, J., Jansen, A., Naber, M., & Einhäuser, W. (2014). Binocular rivalry: frontal activity relates to introspection and action but not to perception. *Journal of Neuroscience*, *34*(5), 1738–1747.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Guldenmund, P., Stender, J., Heine, L., & Laureys, S. (2012). Mindsight: diagnostics in disorders of consciousness. *Critical Care Research and Practice*, *2012*.

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. *Cognition*, *92*(1–2), 67–99. https://doi.org/10.1016/j.cognition.2003.10.011

Hillyard, S. A., Squires, K. C., Bauer, J. W., & Lindsay, P. H. (1971). Evoked Potential Correlates of Auditory Signal Detection. *Science*, *172*(3990), 1357–1360. https://doi.org/10.1126/science.172.3990.1357

Howard, M. A., Volkov, I. O., Mirsky, R., Garell, P. C., Noh, M. D., Granner, M., … Brugge, J. F. (2000). Auditory cortex on the human posterior superior temporal gyrus. *The Journal of Comparative Neurology*, *416*(1), 79–92.

Hubel, D. H., & Wiesel, T. N. (2004). *Brain and visual perception: the story of a 25-year collaboration*. Oxford University Press.

Jayakody, D. M. P., Friedland, P. L., Martins, R. N., & Sohrabi, H. R. (2018). Impact of Aging on the Auditory System and Related Cognitive Functions: A Narrative Review. *Frontiers in Neuroscience*, *12*. https://doi.org/10.3389/fnins.2018.00125

Kaas, J. H., & Hackett, T. A. (1998). Subdivisions of AuditoryCortex and Levels of Processing in Primates. *Audiology and Neurotology*, *3*(2–3), 73–85.

https://doi.org/10.1159/000013783

Kaas, J. H., & Hackett, T. A. (2000). Subdivisions of auditory cortex and processing streams in primates. *Proceedings of the National Academy of Sciences*, *97*(22), 11793–11799. https://doi.org/10.1073/pnas.97.22.11793

King, A. J., & Nelken, I. (2009). Unraveling the principles of auditory cortical processing: can we learn from the visual system? *Nature Neuroscience*, *12*(6), 698–701. https://doi.org/10.1038/nn.2308

Koivisto, M., Lähteenmäki, M., Sørensen, T. A., Vangkilde, S., Overgaard, M., & Revonsuo, A. (2008). The earliest electrophysiological correlate of visual awareness? *Brain and Cognition*, *66*(1), 91–103.

Koivisto, M., & Revonsuo, A. (2003). An ERP study of change detection, change blindness, and visual awareness. *Psychophysiology*, *40*(3), 423–429. https://doi.org/10.1111/1469-8986.00044

Koivisto, M., & Revonsuo, A. (2010). Event-related brain potential correlates of visual awareness. *Neuroscience & Biobehavioral Reviews*, *34*(6), 922–934. https://doi.org/10.1016/j.neubiorev.2009.12.002

Koivisto, M., Revonsuo, A., & Lehtonen, M. (2006). Independence of Visual Awareness from the Scope of Attention: an Electrophysiological Study. *Cerebral Cortex*, *16*(3), 415–424. https://doi.org/10.1093/cercor/bhi121

Koivisto, M., Salminen-Vaparanta, N., Grassini, S., & Revonsuo, A. (2016). Subjective visual awareness emerges prior to P3. *European Journal of Neuroscience*, *43*(12), 1601–1611. https://doi.org/10.1111/ejn.13264

Kral, A., & Eggermont, J. J. (2007). What’s to lose and what’s to learn: Development under auditory deprivation, cochlear implants and limits of cortical plasticity. *Brain Research Reviews*, *56*(1), 259–269. https://doi.org/10.1016/j.brainresrev.2007.07.021

Kral, A., Yusuf, P. A., & Land, R. (2017). Higher-order auditory areas in congenital deafness: Top-down interactions and corticocortical decoupling. *Hearing Research*, *343*, 50–63. https://doi.org/10.1016/j.heares.2016.08.017

Lamme, V. A. (2006). Towards a true neural stance on consciousness. *Trends in Cognitive Sciences*, *10*(11), 494–501.

Lamme, V. A. F. (2004). Separate neural definitions of visual consciousness and visual attention; a case for phenomenal awareness. *Neural Networks*, *17*(5), 861–872. https://doi.org/10.1016/j.neunet.2004.02.005

Lamme, V. A. F. (2010). How neuroscience will change our view on consciousness. *Cognitive Neuroscience*, *1*(3), 204–220. https://doi.org/10.1080/17588921003731586

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences*, *23*(11), 571–579. https://doi.org/10.1016/S0166-2236(00)01657-X

Lamy, D., Salti, M., & Bar-Haim, Y. (2009). Neural Correlates of Subjective Awareness and Unconscious Processing: An ERP Study. *Journal of Cognitive Neuroscience*, *21*(7), 1435–1446. https://doi.org/10.1162/jocn.2009.21064

Laureys, S., Owen, A. M., & Schiff, N. D. (2004). Brain function in coma, vegetative state, and related disorders. *The Lancet Neurology*, *3*(9), 537–546. https://doi.org/10.1016/S1474-4422(04)00852-X

Laureys, S., Pellas, F., Van Eeckhout, P., Ghorbel, S., Schnakers, C., Perrin, F., … Goldman, S. (2005). The locked-in syndrome : what is it like to be conscious but paralyzed and voiceless? In S. Laureys (Ed.), *Progress in Brain Research* (pp. 495–611). https://doi.org/10.1016/S0079-6123(05)50034-7

Lewis, C. I. (1956). *Mind and the world-order: Outline of a theory of knowledge*. Courier Corporation.

Luck, S. J. (2014). *An introduction to the event-related potential technique*. MIT press.

Merzenich, M. M., & Brugge, J. F. (1973). Representation of the cochlear partition on the superior temporal plane of the macaque monkey. *Brain Research*, *50*(2), 275–296. https://doi.org/10.1016/0006-8993(73)90731-2

Moore, B. C. (2012). *An introduction to the psychology of hearing*. Brill.

Naci, L., Monti, M. M., Cruse, D., Kübler, A., Sorger, B., Goebel, R., … Owen, A. M. (2012). Brain–computer interfaces for communication with nonresponsive patients. *Annals of Neurology*, *72*(3), 312–323. https://doi.org/10.1002/ana.23656

Nagel, T. (1974). What Is It Like to Be a Bat? *The Philosophical Review*, *83*(4), 435. https://doi.org/10.2307/2183914

Nelken, I., Fishbach, A., Las, L., Ulanovsky, N., & Farkas, D. (2003). Primary auditory cortex of cats: feature detection or something else? *Biological Cybernetics*, *89*(5), 397–406. https://doi.org/10.1007/s00422-003-0445-3

Niedeggen, M., Wichmann, P., & Stoerig, P. (2001). Change blindness and time to consciousness. *European Journal of Neuroscience*, *14*(10), 1719–1726. https://doi.org/10.1046/j.0953-816x.2001.01785.x

Nowak, L. G., & Bullier, J. (1997). The Timing of Information Transfer in the Visual System. In K. S. Rockland, J. H. Kaas, & A. Peters (Eds.), *Extrastriate Cortex in Primates* (pp. 205–241). https://doi.org/10.1007/978-1-4757-9625-4_5

Parasuraman, R., & Beatty, J. (1980). Brain events underlying detection and recognition of weak sensory signals. *Science*, *210*(4465), 80–83. https://doi.org/10.1126/science.7414324

Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1–2), 8–13.

Revonsuo, A. (2009). *Consciousness: the science of subjectivity*. Psychology Press.

Romanski, L. M., Tian, B., Fritz, J., Mishkin, M., Goldman-Rakic, P. S., & Rauschecker, J. P. (1999). Dual streams of auditory afferents target multiple domains in the primate prefrontal cortex. *Nature Neuroscience*, *2*(12), 1131–1136. https://doi.org/10.1038/16056

Rosenthal, D. M. (2002). How many kinds of consciousness? *Consciousness and Cognition*, *11*(4), 653–665.

Salin, P.-A., & Bullier, J. (1995). Corticocortical connections in the visual system: structure and function. *Physiological Reviews*, *75*(1), 107–155.

Salti, M., Bar-Haim, Y., & Lamy, D. (2012). The P3 component of the ERP reflects conscious perception, not confidence. *Consciousness and Cognition*, *21*(2), 961–968.

Schankin, A., & Wascher, E. (2007). Electrophysiological correlates of stimulus processing in change blindness. *Experimental Brain Research*, *183*(1), 95–105. https://doi.org/10.1007/s00221-007-1023-z

Schnakers, C., Vanhaudenhuyse, A., Giacino, J., Ventura, M., Boly, M., Majerus, S., … Laureys, S. (2009). Diagnostic accuracy of the vegetative and minimally conscious state: Clinical consensus versus standardized neurobehavioral assessment. *BMC Neurology*, *9*, 35. https://doi.org/10.1186/1471-2377-9-35

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature Neuroscience*, *8*(10), 1391.

Squires, K. C., Hillyard, S. A., & Lindsay, P. H. (1973). Vertex potentials evoked during auditory signal detection: Relation to decision criteria. *Perception & Psychophysics*, *14*(2), 265–272. https://doi.org/10.3758/BF03212388

Steffen, H., Simonis, C., Thomas, H., Tillein, J., & Scheich, H. (1988). Auditory Cortex: Multiple Fields, their Architectonics and Connections in the Mongolian Gerbil. In J. Syka & R. B. Masterton (Eds.), *Auditory Pathway: Structure and Function* (pp. 223–228). https://doi.org/10.1007/978-1-4684-1300-7_33

Tsuchiya, N., Wilke, M., Frässle, S., & Lamme, V. A. F. (2015). No-Report Paradigms: Extracting the True Neural Correlates of Consciousness. *Trends in Cognitive Sciences*, *19*(12), 757–770. https://doi.org/10.1016/j.tics.2015.10.002

Wiens, S. (2007). Concepts of visual consciousness and their measurement. *Advances in Cognitive Psychology*, *3*(1–2), 349–359. https://doi.org/10.2478/v10053-008-0035-y