The ecological cocktail party: Measuring brain activity during an auditory oddball task with background noise

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Abstract

Most experiments using EEG recordings take place in highly isolated and restricted environments, limiting their applicability to real-life scenarios. New technologies for mobile EEG are changing this by allowing EEG recording to take place outside of the laboratory. However, before results from experiments performed outside the laboratory can be fully understood, the effects of ecological stimuli on brain activity during cognitive tasks must be examined. In this experiment, participants performed an auditory oddball task while also listening to concurrent background noises of silence, white noise and outdoor ecological sounds, as well as a condition in which the tones themselves were at a low volume. We found a significantly increased N1 and decreased P2 when participants performed the task with outdoor sounds and white noise in the background, with the largest differences in the outdoor sound condition. This modulation in the N1 and P2 replicates what we have previously found outside while people ride bicycles (Scanlon et al., 2017). No behavioural differences were found in response to the target tones. We interpret these modulations in early ERPs as indicative of sensory filtering of background sounds, and that ecologically valid sounds require more filtering than synthetic sounds. Our results reveal that much of what we understand about the brain will need to be updated as we step outside the lab.

1. Introduction

Historically, experiments in cognitive neuroscience tend to require participants to experience highly isolated conditions, for two main reasons. The first is to control any effects that the environment may have on normal brain activity. The second is due to equipment limitations that make recording outside of the laboratory difficult and prone to large degrees of data noise. However since these equipment limitations have often made it difficult or impossible to test brain activity in different environments, the effects of ecologically valid environmental influences on brain activity have received little attention. New technologies are beginning to change this, with new mobile EEG technologies that can be carried almost anywhere (Debener, Minow, Emkes, Gandras, & de Vos, 2012; de Vos, Gandras, & Debener, 2014; Zink, Hunyadi, Van Huffel, and de Vos 2016; Krigolson et al., 2017). At this point, few studies have attempted to determine what effect natural environmental noise may have on brain activity. The present study was conducted to simulate some types of natural sound environments in order to determine the effect of environmental sounds may have on brain activity and the ERP.

Several studies have used mobile EEG to perform experiments in real-life environments. Debener et al. (2012) used a wireless EEG system while participants performed an auditory oddball task either while sitting indoors or walking outdoors. They were able to show that P3 amplitude was significantly larger when generated while sitting indoors than while walking outdoors. Zink et al. (2016) had participants performing an auditory oddball task during mobile cycling, stationary pedaling and sitting in a natural outdoor environment. The authors found no difference in P3 amplitude between the stationary cycling and sitting conditions, but demonstrated a near-significantly reduced P3 amplitude while participants were cycling. Recently in our lab, we had participants both sitting and pedaling on a stationary bicycle inside

the lab and found no P3 differences during the auditory oddball task (Scanlon, Sieben, Holyk, & Mathewson, 2017a). Next we had participants performing an auditory oddball task both while cycling outside and while sitting inside. Again, we found a significantly reduced P3 during the mobile task of cycling. However we were surprised to find a significantly decreased P2 and increased N1 while participants had been cycling outside (Scanlon, Townsend, Cormier, Kuziek & Mathewson, 2017b). Taken together, these studies indicate that while divided attention appears to have an effect on the P3, there is no evidence that the environment affects this component. However, the increased N1 and decreased P2 while participants cycled outside led us to the current study to try to isolate this effect inside the lab.

As this previous study was primarily exploratory, there are several possible reasons for these changes in the N1 and P2 components of the ERP while participants had been cycling outside (Scanlon, et al., 2017b). In the outdoor condition, participants were also cycling, as opposed to sitting in the indoor condition. This meant that they were experiencing a physical (however sub-aerobic) mobile activity, visual optic flow, as well as auditory stimuli that they did not experience while sitting inside the laboratory. However, the modulations in the N1 and P1 were not observed when participants biked on a stationary bike inside the lab (Scanlon et al., 2017a). Additionally, Scanlon et al. (2017b) found that alpha power was decreased while participants cycled outside, and previous work by Brandt, Jansen & Carbonari (1991) has shown that alpha power may be positively correlated with visual N1 and P2 amplitudes. However, most literature concerning the auditory N1 and P2 components point to these components being mostly affected by auditory factors, especially for a task in the auditory modality (Näätänen & Picton, 1987).

The N1-P2 complex appears to reflect pre-attentive sound processing in the auditory cortex (Näätänen & Picton, 1987). The P1, N1 and P2 components which make up this complex have been shown to reflect several nearly simultaneous processes originating within or near the primary auditory cortex (Näätänen & Picton, 1987; Wolpaw and Penry, 1975; Wood & Wolpaw, 1982). The auditory N1 is a negative-going waveform with three subcomponents, which peak approximately between 75 and 150 ms after stimulus onset (Luck, 2014). The N1 wave appears to be sensitive to attention, and is modulated by how well an attended stimulus can be distinguished from other stimuli by physical cues such as pitch or location (Näätänen, 1982, 1992). The P2 component, on the other hand, is a positive-going waveform which occurs approximately 150-275 ms after stimulus onset as the second positive component of the ERP (Dunn, Dunn, Languis & Andrews, 1998). P2 is believed to represent a top-down, higher-order aspect of perceptual processing, which is also modulated by attention (Luck & Hillyard, 1994; Freunberger, Klimesch, Doppelmayr & Höller, 2007; Hackley, Woldorff, & Hillyard, 1990). Therefore, it appears that this change in the N1 and P2 components relates to some auditory aspect of top down perceptual processing and attention that is altered when participants performed the same task in a rich and noisy environment (Scanlon, et al., 2017b).

Perhaps some aspect of an outdoor environment changes the attentional and sensory processes required to perform an auditory task. This could be due to the overlapping sounds, as one filters unimportant background stimuli to focus on their current task. Conversely, the reason could also be as simple as the possibility that the same headphone task sounded subjectively quieter in an open environment. In the current study, we intend to investigate these possibilities by having participants perform the same headphone auditory oddball task as in previous studies (Scanlon et al., 2017a; Scanlon et al., 2017b) with the following conditions: background outdoor

traffic sounds, background white noise, silent background, and silent background with quieter tones. Evidence from the literature leads us to hypothesize that the effect within the N1 and P2 in our previous study was due to a process of filtering out extraneous ambient noise, while focusing in on the relevant task. Therefore we hypothesize that we will be able to most effectively replicate the increase in N1 and decrease in P2 when outdoor sounds are played in the background.

2. Methods

2.1 Participants

A total of fourteen members of the university community participated in the experiment (Mean age=21.6; Age range=18-26; Sex=5 female). Six participants were members or associated members of The Mathewson Lab at the University of Alberta. All participants were either compensated $10/hr or received course credit for participating in the experiment. Participants all had normal or corrected-to-normal vision with no history of neurological problems. The experimental procedures were approved by the Internal Research Ethics Board of the University of Alberta and participants gave informed consent prior to participating.

2.2 Materials

In all conditions, participants were seated in a radio frequency attenuated chamber in front of a 1920 x 1080 pixel ViewPixx/EEG LED monitor running at 120 Hz with simulated-backlight rastering. A fixation cross was presented using a windows 7 PC running Matlab 2012b with the Psychophysics toolbox. Video output was via an Asus Striker GTX760 and audio output was through an Asus Xonar DSX sound card. The participants pressed a button with their right index finger when they heard the high oddball tone. Responses from the button press were

marked in the EEG data by the Raspberry Pi 2 model B computer.

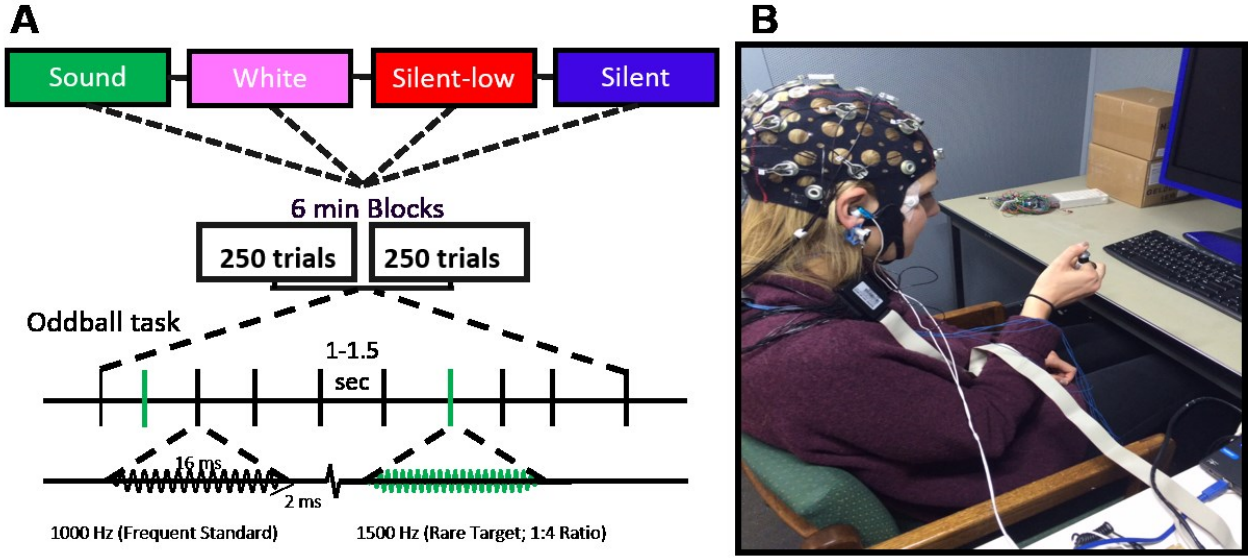

Figure 1 EEG apparatus and procedure.
A: During each of the noise conditions, participants performed two 6-minute blocks of an auditory oddball task, with self-paced breaks in between. Within the task, 80% of the tones were frequent low-pitched tones (1000 Hz), and 20% were rare high-pitched tones (1500 Hz). Each tones was played for 16 ms with a ramp-up and down of 2 ms. Tones were played 1-1.5 seconds apart. B: The task was performed in a Faraday cage with the participant wearing an EEG cap and responding to target tones with a hand-held button connected to the Raspberry Pi.

2.3 Procedure

Each participant completed an auditory oddball task in four conditions: *silent*, *outside sounds*, *white noise*, and *silent-low* (Figure 1). For the oddball task, a pair of Sony MDR-E10LP headphones played one of two different frequency tones (either 1500 or 1000 Hz; sampled at 44.1 kHz; two channel; 16-ms duration; 2-ms linear ramp up and down; 65 Db). A pair of Logitech Z130 speakers played the outdoor sounds and white noise clip.

Condition order was counterbalanced across participants and they completed eight 6 minute blocks of 250 trials for a total of 2000 trials. Each trial had a 1/5 likelihood of being a target trial. Each block began with a 10-second countdown to ensure the oddball task only took

place when the participant was ready and when the necessary sounds were playing. Each trial also began with a pre-tone interval between 1000 and 1500ms, followed by the tone onset. The next trial began immediately after the tone offset, with participants responding to targets during the following pre-tone interval.

A Raspberry Pi 2 model B computer, which was running version 3.18 of the Raspbian Wheezy operating system, using version 0.24.7 of OpenSesame software (Mathôt, Schreij, & Theeuwes, 2012), was used both to run the oddball task and to mark the EEG for ERP averaging (Kuziek, Shein, and Mathewson, 2017). Audio output was via a 900 MHz quad-core ARM Cortex-A7 CPU connected through a 3.5 mm audio connector. Coincident in time with sound onset, 8-bit TTL pulses were sent to the amplifier by a parallel port connected to the General Purpose Input/Output (GPIO) pins to mark the data for ERP averaging. A start button was affixed to the Raspberry Pi to simplify the beginning of a block. The participant's task was to press the target button with their right hand when the rare tone was heard while keeping their eyes on a fixation cross.

2.4 Conditions

In the *silent* condition the participants were asked to perform the oddball task with no background noise. In the *outside sounds* condition, a 6 minute recording of sounds taken next to a noisy roadway (available upon request) was played in the background, with a maximum volume of 84 dB (Min 55 dB; tones played at 65 dB). The sounds were recorded on an iPhone 5, voice memos app from the same location the previous bike study took place (Scanlon et al., 2017b; bike path along Saskatchewan Dr. NW, Edmonton, Canada; between 116 St and 111 St) in December 2015. In the *white noise* condition an even band of frequencies was played in the

background at a volume of 54 dB for 6 minutes. In the *silent-low* condition, no sounds were played in the background, and the oddball task itself was played at a decreased volume of 54 dB.

2.5 EEG Recording

Based on Mathewson, Harrison, & Kizuk's (2015) previous lab work directly comparing overall electrode quality (noise levels, statistical power etc.) active amplified wet electrodes (BrainProducts actiCAP) were selected for the study. Ag/AgCl pin electrodes were used and arranged in 10-20 positions (Fp2, F3, Fz, F4, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, and Oz). Additionally, a ground electrode, embedded in the cap at position Fpz, and two reference electrodes, clipped to the left and right ear, were used (referenced online to the right ear). SuperVisc electrolyte gel and mild abrading of the skin with the blunted syringe tip were used to lower impedances of all the electrodes. Gel application and aforementioned techniques continued until impedances were lowered to < 10 kΩ, measured using an impedance measurement box (BrainProducts) and until data quality appeared clean and reduced of noise. In addition to the 15 EEG sensors, 2 reference electrodes, and the ground electrode, the vertical and horizontal bipolar electrooculogram was recorded from passive Ag/AgCl easycap disk electrodes affixed above and below the left eye, and 1 cm lateral from the outer canthus of each eye. NuPrep preparation gel was applied to the applicable areas of the face, followed by wiping of the skin using an antibacterial sanitizing wipe, both used to lower the impedance of these EOG electrodes based on visual inspection of the data. These bipolar channels were recorded using the AUX ports of the V-amp amplifier, using a pair of BIP2AUX converters, and a separate ground electrode affixed to the central forehead.

EEG was recorded with a Brain Products V-amp 16- channel amplifier. Data were digitized at 500 Hz with a resolution of 24 bits. Data were filtered with an online bandpass with

cutoffs of 0.1 and 30 Hz, along with a notch filter at 60 Hz. Data was recorded using a Microsoft Surface Pro 3 running Brain Vision Recorder, and powered along with the Raspberry Pi by an Anker Astro Pro2 20000 mAh Multi-Voltage External Battery. The mentioned technology was connected to the Surface Pro 3 using a Vantec 4-Port USB 3.0 Hub.

Trials took place in a dimly lit sound and radio frequency attenuated chamber, with copper mesh covering the window. The fan and lights were turned on, to allow proper ventilation and visual acuity of the fixation. The monitor runs on DC power from outside the chamber, the keyboard and mouse plugged into USB outside the chamber, and the speakers and amplifier were both powered from outside the chamber. Nothing was plugged into the internal power outlets. Any devices transmitting or receiving radio waves (i.e., cellphones) were removed from the chamber for the duration of the experiment.

2.5. EEG analysis

EEG analyses were computed using MATLAB 2012b with EEGLAB (Delorme & Makeig, 2004), as well as custom scripts. After recording, EEG data was re-referenced to the average of the left and right ear lobe electrodes. Timing of the TTL pulse was marked in the EEG data during recording, and used to construct 1200-ms epochs (including the 200-ms pretrial baseline) which were time-locked to the onset of standard and target tones. The average voltage in the first 200-ms baseline period was subtracted from the data for each electrode and trial. To remove artifacts caused by movement, amplifier blocking, and any other non-physiological factors, any trials in either of the conditions with a voltage difference from baseline larger than ±1000 μV on any channel (including eye channels) were removed from further analysis. Following eye correction, a second threshold was applied to remove any trials with a voltage difference from baseline of ±500 μV. Over 98 percent of trials were retained after this procedure

in each condition. On average, artifact rejection left approximately equal numbers of trials per participant in the sound (M_{targ} = 99.929 $range_{targ}$ = 99-100; SD_{targ}= 0.267; M_{stand} = 398; $range_{stand}$ = 386-400; SD_{stand} = 3.762), white noise (M_{targ} = 99.5; $range_{targ}$ = 97-100; SD_{targ} = 1.092; M_{stand} = 397.1429; $range_{stand}$ = 382-400; SD_{stand} = 5.682), silent-low (M_{targ} = 99.714; $range_{targ}$ = 97-100; SD_{targ} = 0.825; M_{stand} = 397.643; $range_{stand}$ = 378-400; SD_{stand} = 6.0461), and silent (M_{targ} = 99.571; $range_{targ}$ = 96-100; SD_{targ} = 1.158; M_{stand} = 398; $range_{stand}$ = 381-400; SD_{stand} = 5.054; SD = Standard Deviation) from which we computed the remaining analyses.

A regression-based eye-movement correction procedure was used to estimate and remove variance due to artifacts in the EEG due to blinks, as well as vertical and horizontal eye movements (Gratton et al., 1983). This technique identifies blinks with a template-based approach, then computes propagation factors such as regression coefficients, predicting the horizontal and vertical eye channel data from the signals at each electrode. This eye channel data is then subtracted from each channel, weighted by these propagation factors, allowing us to remove most variance in the EEG which can be predicted by eye movements. No further rejection or filtering was done on the data in order to include as many trials as possible for all conditions, as well as to investigate how minor sources of non-eye-related noise contribute to the power to measure ERP components during the outdoor cycling task.

3. Results

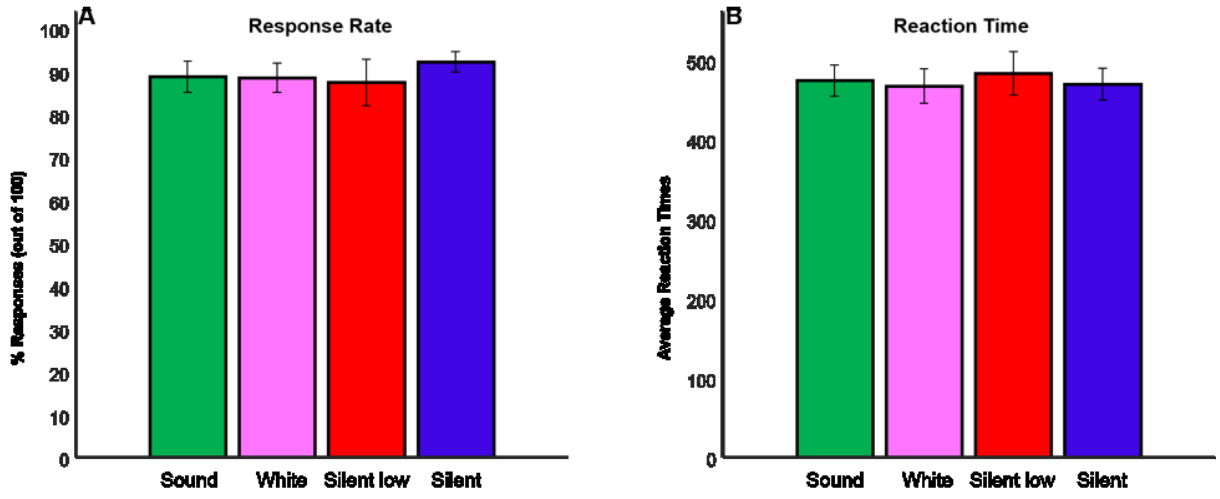

Figure 2 Behavioural analysis.
A: Bar graph depicting mean and standard error for the percentage of targets that received a response within 2 seconds after tone onset across participants for both conditions. B: Bar graph depicting the mean and standard error for the average response time (with missed responses removed) across participants for each condition.

3.1 Behavioural differences

A bar graph of the response rate and reaction time is depicted in Figure 2A and B. To test for differences in response rate and average reaction time to targets in each condition, one-way repeat-measures ANOVA tests with Greenhouse-Geisser correction were performed, revealing no significant group differences in the response rate ($F(3,13) = 0.913$, $p = 0.355$) or mean response time ($F(3,13) = 1.229$, $p = 0.273$).

3.2 ERP morphology and topography

Figure 3A depicts grand average ERPs calculated from each participant's artifact-removed and corrected target and standard tones at electrode Pz. Shaded regions represent the standard error of the mean for each time point. Evident from the plots is the expected increase in P3 amplitude during target trials in the central posterior topographical regions (Pz; Figure 3B).

This expected oddball task difference in the P3 is shown with increased positive voltage between 300 and 430 ms following the rare target tones, compared the frequent standard tones. We continued to use this time window for all further analysis of the P3.

Figure 4A (left) plots the target-standard difference for each condition at electrode Fz. Evident from the plot is a target-standard difference in the MMN/N2b time window, with an increase in negative voltage between 175 and 275 ms following the rare target tones compared to frequent standard tones. Also evident in Figure 3B is that this difference appears to be visibly maximal at fronto-central electrodes. Therefore, this time window at electrode Fz was used for further analysis of the MMN/N2b.

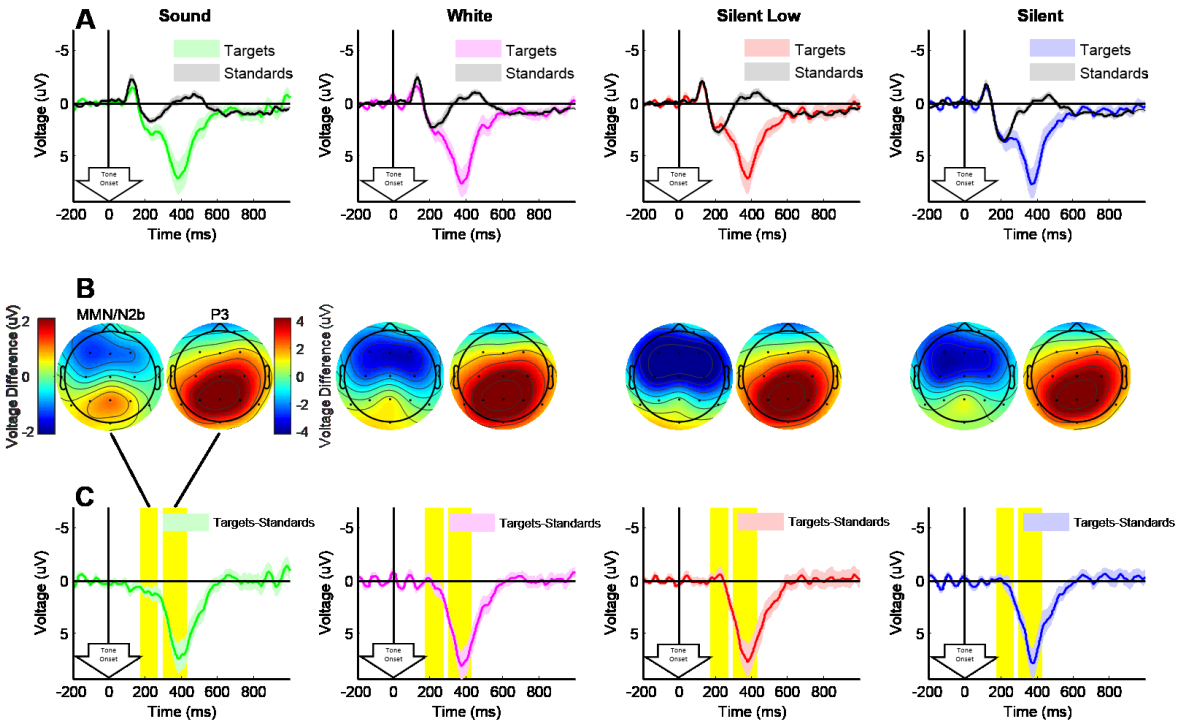

Figure 3 Grand average ERPs.

Grand average ERPs. A: Grand-average ERPs computed at electrode Pz for all eye movement corrected and artefact-removed trials, for both target (colour) and standard (black) tones. B: Scalp topographies for grand-average ERP difference between target and standard tones in the MMN/N2b and P3 time windows (highlighted in yellow), 175-275 ms and 300-430 ms after the tones, respectively. C: ERP difference wave from electrode Pz for both, with shaded regions representing within-subject standard error of the mean for mean for this difference, with between-subjects differences removed (Loftus & Masson, 1994). Yellow highlighted regions depict the time window for the MMN/N2b and P3 analysis as well as topographical plots.

Figure 3B depicts topographies of the target-standard differences within the MMN/N2b and P3 time windows. The MMN/N2b time window topography shows the expected activation distribution toward the front of the scalp for all four conditions, while the P3 topographies demonstrate the expected posterior scalp activation distributions. Figure 3C depicts the ERP difference waves at electrode Pz, which are created through the subtraction of the standard tone ERPs from the target tone ERPs for each subject. Shaded regions depict the within-participant standard error of the mean, with variation between participants removed by the target - standard subtraction. This error estimation is therefore equivalent to that used in the t-test of the target-standard difference from zero (Loftus & Masson, 1994).

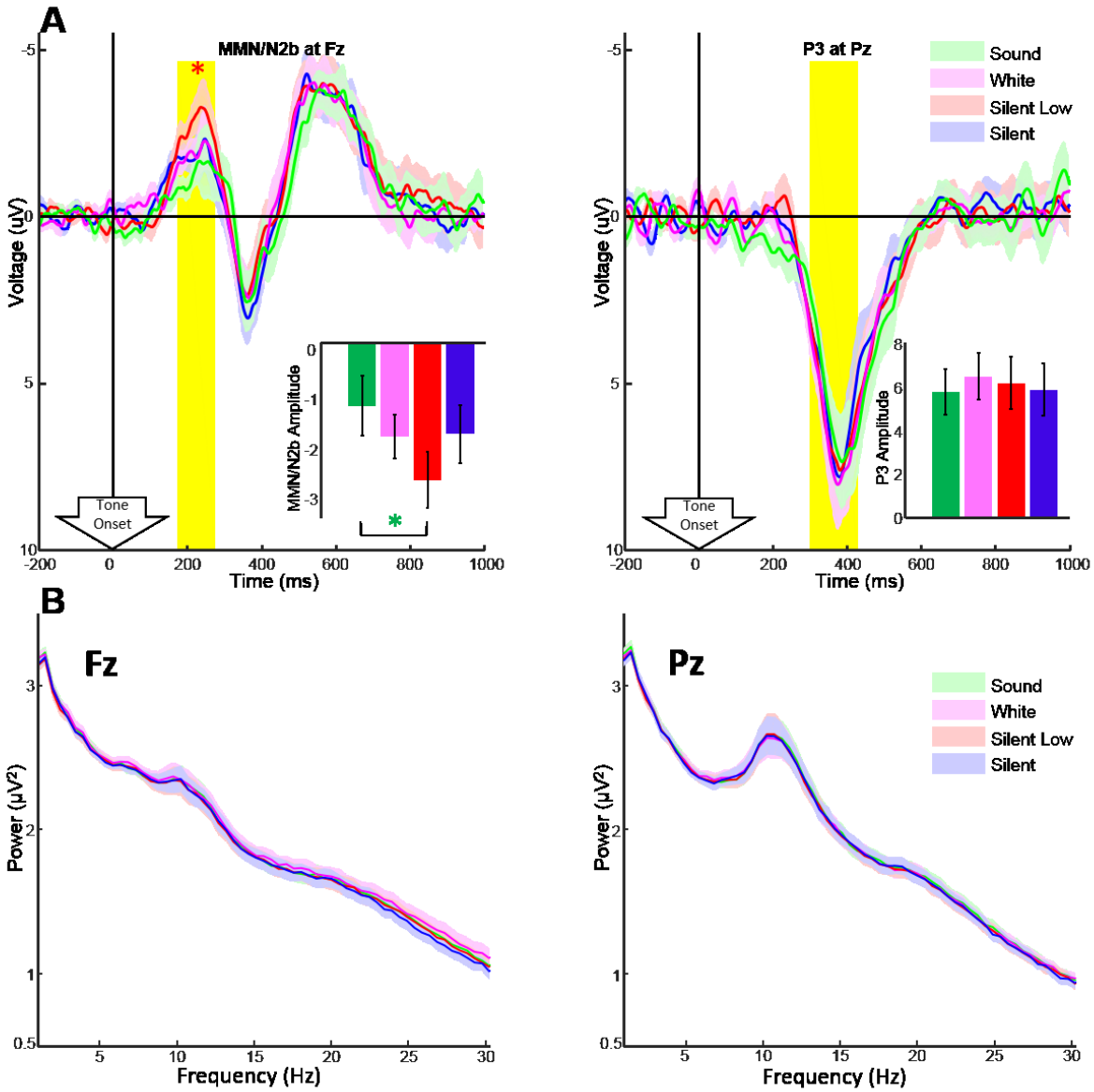

Figure 4 Difference waves and spectral analysis.
A: Difference waves indicating the average difference between target and standard trials for all four conditions are plotted for the Fz and Pz electrode locations. Yellow highlighted regions depict the main time windows compared, particularly the MMN/N2b at Fz (left) and the P3 at Pz (right). Inset bar graph indicate the mean and standard error across participants for the highlighted time window in each plot, for each condition. B: Single-trial EEG spectra from electrodes Fz and Pz. This was calculated with zero-padded FFTs on 290 auditory standard trial epochs for each subject, averaged over trials, then subjects. Shaded regions indicate the standard error of the mean. Red asterisks denote significant differences, while green asterisks denote a marginal difference.

All conditions showed a clear negative peak at approximately 230 ms at the Fz electrode (Figure 4A). To test for a significant MMN/N2b effect within each condition, we ran a one-tailed, paired samples *t*-test comparing the MMN/N2b at electrode Fz averaged over the 175-275 ms time window centered around this peak to zero. The test revealed a significant MMN/N2b effect in all four conditions (*Outdoor sounds*: M_{diff}= -1.272; SD_{diff}= 2.224; $t(13) = -2.139$; p= 0.026; *White*: M_{diff}= -1.889; SD_{diff}= 1.644; $t(13) = -4.300$; p= 4.318e-04; *Silent-low*: M_{diff}= -2.760; SD_{diff}= 2.109; $t(13) = -4.897$; p= 1.458e-04; *Silent*: M_{diff}= -1.835; SD_{diff}= 2.184; $t(13) = -3.143$; p= 0.004).

Additionally, Figure 4A revealed a clear positive peak as expected at approximately 380 ms at electrode Pz for each condition. To test for a P3 effect within each condition, a one-tailed paired samples t-test was used to compare this P3 difference averaged over the 300-430 ms time window at the Pz electrode to zero. This test revealed a significant P3 effect in the *outdoor sounds* (M_{diff}= 5.739; SD_{diff}= 3.948; $t(13) = 5.439$; p= 5.666e-05), *white noise* (M_{diff}= 6.459; SD_{diff}= 3.956; $t(13) = 6.109$; p= 1.863e-05), *silent-low* (M_{diff}= 6.152; SD_{diff}= 4.445; $t(13) = 5.179$; p= 8.88e-05), and *silent* (M_{diff}= 5.837; SD_{diff}= 4.463; $t(13) = 4.893$; p= 1.469e-04) conditions.

Figure 4A depicts difference waves plotted for all four conditions at the Fz and Pz electrodes to allow for group comparisons. Evident from the plots is no significant differences in P3 target-standard difference between any of the four conditions at Pz. To test for group differences in the P3 difference at electrode Pz, a repeated measures one-way ANOVA with a Greenhouse-Geisser correction was used, revealing no significant differences ($F(3,13) = 0.713$, $p = 0.474$). Also evident from the Figure 4A plots is a larger MMN/N2b amplitude standard-target difference for the *silent-low* condition at electrode Fz. The same test was used to test for

group differences within the MMN/N2b time window at electrode Fz, revealing significant group differences ($F(3,13) = 3.845$, $p = 0.0373$). To investigate this difference, six two-way paired and Bonferroni corrected ($\alpha = 0.0083$) t-tests were used, revealing that the difference was driven by a larger MMN/N2b amplitude in the *silent-low* condition compared to the *outside sounds* and *silent* conditions. The target-standard difference within the MMN/N2b time window at Fz for the *silent-low* condition was found to be marginally higher than *silent* (Mdiff= -0.9258; SDdiff= 1.2440; $t(13) = -2.7845$; $p=0.0155$) condition. No other differences were found for the MMN/N2b.

Because there is some possibility that the MMN and N2b differentially contribute to the MMN/N2b effect (Scanlon et al., 2017), we separated this time window in order to analyze averages of the early MMN time window (100-200 ms) and the later N2b time window (200-300 ms). We found no significant group differences when the repeated measures one-way Greenhouse-Geisser corrected ANOVA was applied to the MMN (at Fz: $F(3,13) = 1.397$, $p = 0.248$; at Pz: $F(3,13) = 1.608$, $p = 0.211$) or the N2b time window (at Fz: $F(3,13) = 2.268$, $p = 0.122$; at Pz: $F(3,13) = 0.889$, $p = 0.386$). It is possible that both the MMN and N2b were elicited within this time window, however the current design does not allow us to disentangle these components from each other.

3.3 N1 and P2 Amplitudes

In order to observe the effects of the four different sound conditions on general stimulus processing, grand averaged ERPs were separated into standards and targets for each condition at the Fz electrode and plotted in Figure 5B. A visual inspection of the plots in Figure 5B indicates increased amplitude in the N1 component (100-175 ms) for the *outside sound*, *white noise* and *silent-low* conditions for the standards and targets at Fz. To test for significant differences for the

N1 time window, one-way repeated measures ANOVA tests with Greenhouse-Geisser corrections were used, revealing significant group differences for the N1 at Fz within standard ($F(3,13) = 11.607$, p=3.90e-04) and target ($F(3,13) = 3.668$, p=0.044) trials. Within standard trials, six pair-wise Bonferroni corrected ($\alpha = 0.0083$) t-tests were used to determine the cause of group effects, demonstrating that the difference was driven by a difference between the silent condition and all three of the sound-altered conditions. The silent condition was found to have a significantly smaller amplitude N1 compared to the *outside sound* (Mdiff= -1.683; SDdiff=1.029; $t(13) = -6.116$; p=3.682e-05), *white noise* (Mdiff= -1.319; SDdiff=1.115; $t(13) = -4.424$; p=6.872e-04) and *silent-low* (Mdiff= -0.901; SDdiff=0.957; $t(13) = -3.519$; p=0.004) conditions. Within target trials again we used six pair-wise Bonferroni corrected ($\alpha = 0.0083$) t-tests to determine the cause of group effects. Within target trials at Fz, a marginally significant difference at N1 was found in which the *outside sound* condition was significantly larger than the *silent* condition (Mdiff= -1.093; SDdiff=1.316; $t(13) = -3.106$; p=0.0083).

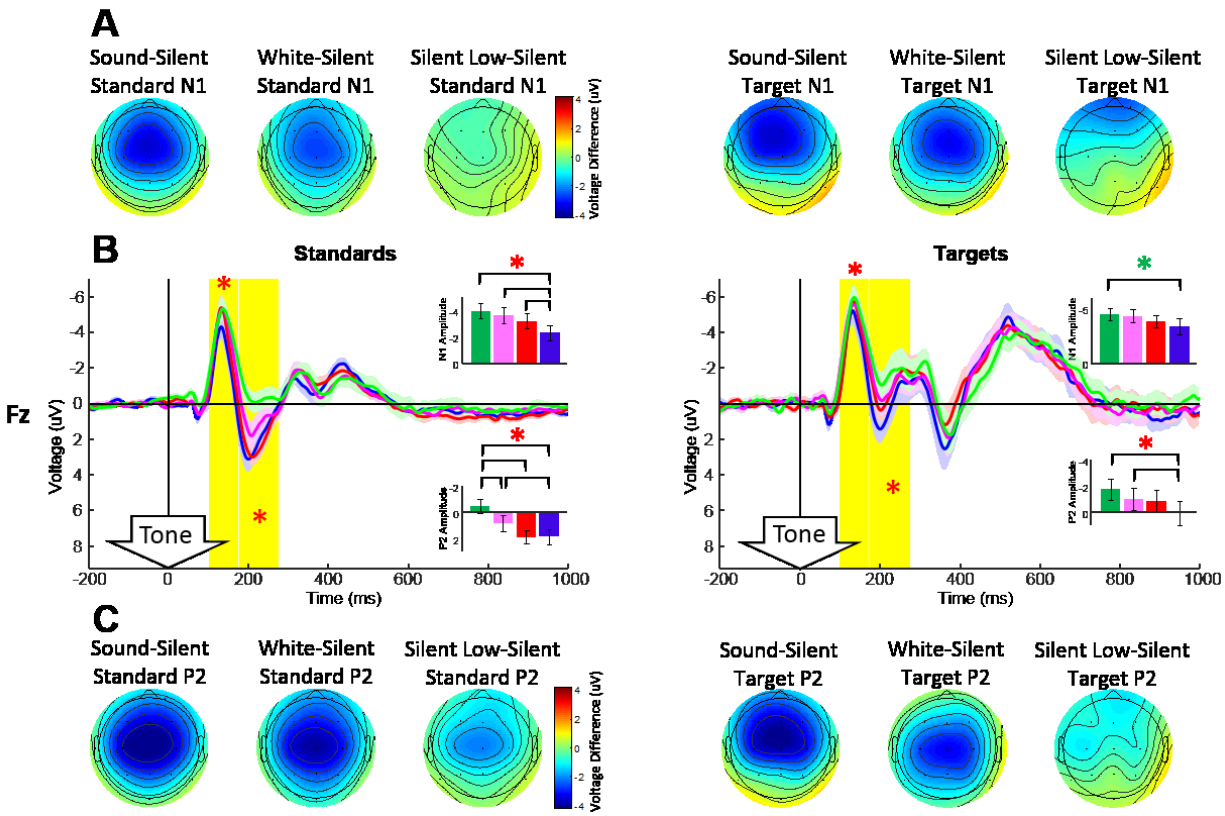

Figure 5 Grand average ERPs
A: Topographies for the N1 time window comparing each condition to the silent background condition. B: Grand average ERPs collected at the Fz electrode location, plotted separately to compare within standards and targets between conditions. Shaded regions indicate the standard error of the mean. Inset bar graphs show the mean and standard error across participants in the N1 and P2 time windows. C: Topographies for the P2 time window comparing each condition to the silent background condition. Red asterisks denote significant differences, while green asterisks denote a marginal difference.

Visual inspection of Figure 5B at the P2 time window (175-275 ms), reveals an increased positive voltage for the *silent* condition compared to the sound, *white noise* and sometimes the *silent-low* condition. To test for significant differences in the P2 time window at Fz, a one-way repeated measures ANOVA with Greenhouse-Geisser correction was performed, revealing

significant group differences for both standard (F(3,13) = 23.474, *p* = 4.216e-07) and target (F(3,13) = 7.552, *p* = 0.0015) trials. Within standard trials at Fz, we used six pair-wise Bonferroni corrected ($\alpha = 0.0083$) t-tests to determine the cause of group effects, finding significant differences between several conditions. The P2 amplitude during the sound condition was significantly lower than the *white noise* (Mdiff=-1.333; SDdiff=1.033; t(13) =-4.826; *p*=0.000331), *silent-low* (Mdiff=-2.362; SDdiff=1.344; t(13) =-6.576; *p*=1.781e-05) and *silent* (Mdiff=-2.348; SDdiff=1.209; t(13) =-7.264; *p*=6.327e-06) conditions. Additionally, the standard P2 amplitude for the *white noise* condition was significantly lower than in the *silent* condition (Mdiff=-1.015; SDdiff=1.103; t(13) =-3.443; *p*=0.00437). Another set of six Bonferroni corrected ($\alpha = 0.0083$) paired t-tests were performed to determine the cause of the group effects for the P2 at Fz in target trials, revealing that this effect was driven by the *silent* condition having a significantly higher P2 amplitude than the *outside sound* (Mdiff=-1.7852; SDdiff=1.558; t(13) =-4.2872; *p*=0.0008840) and *white noise* (Mdiff=-1.0699; SDdiff=1.122; t(13) =-3.5678; *p*=0.003437) conditions. In summary, the P2 amplitude was significantly reduced for the *outside sounds* and *white noise* conditions compared to the *silent* condition for both standards and targets at electrode Fz.

3.4 Spectral differences

Figure 4B shows the grand average spectra for the Fz and Pz electrodes. This plot was made from a random sample of 370 of each participant's artefact-removed standard trials. These trials were then used to calculate a fast Fourier transform (FFT) through a procedure of symmetrically padding the 600 time point series with zeros, making a 1,024-point time series for each epoch, providing .488 Hz frequency bins. Because the data were collected with an online low-pass filter of 30 Hz, only frequencies measuring up to 30 Hz were plotted. We then

calculated the spectra for each participant by calculating the average of the 370 spectra for each participant, and then combining these into a grand average spectra. Shaded regions indicate the standard error of the mean across participants. Evident from the plots, all four conditions show the expected 1/frequency structure in the data. Also evident are no significant differences in any frequency. To test for differences in alpha power, a one-way repeated measures ANOVA with Greenhouse-Geisser correction was performed in both the Fz and Pz electrode locations, indicating no significant group differences for either the Fz ($F(3,13) = 1.351$, $p = 0.254$) or Pz ($F(3,13) = 0.025$, $p = 0.759$) electrodes.

4. Discussion

In this study we compared ERPs during an oddball task in four conditions: with background traffic sounds (*outdoor sounds*), background white noise (*white noise*), silent background with quiet tones (*silent-low*), and silent background (*silent*). We found that we were able to replicate the main findings of a previous study (Scanlon et al., 2017b) in which an increased N1 and decreased P2 were observed while participants biked outside. In particular, when we played a recording of *outdoor sounds* in the background while participants performed a headphone auditory oddball task, the N1 was increased and the P2 was decreased compared to the *silent* condition. This indicates that these sounds had an effect on the sensory processing involved with the auditory task. The present paper was also able to look at reaction time and response rate, finding no behavioural differences between the conditions. Additionally, the *white noise* condition had a similar effect to a lesser extent, indicating that a simple, unchanging background sound can have a similar effect on sensory processes. Finally, the *silent-low* condition, in which the tones themselves were played at a quieter volume also appeared to have an effect, but only at the N1, indicating that a quiet task volume may also have some effect on

these sensory processes. While we cannot say for certain that no other factors played a part in the N1-P2 effect found in the first study (Scanlon et al., 2017b), we can determine that background noises were at least sufficient to replicate this effect.

4.1 Alpha power

We investigated changes in alpha power for the differing sound conditions because previous studies have indicated that alpha power can influence N1 and P2 amplitudes (Brandt, Jansen & Carbonari, 1991; Jansen, & Brandt, 1991). However, in this study, no differences in alpha power were found between conditions, demonstrating that the effects within the N1 and P2 were independent of alpha power. A previous mobile EEG study from this lab did show a marginal difference in alpha power while participants cycled outside compared to sitting inside (Scanlon et al., 2017b), however this is presumably due to the increase in awareness to visual stimuli present while participants cycled outside. Alpha is known to reflect an individual's state of awareness (Mathewson et al., 2011), as it has been demonstrated to increase with decreasing attentional focus, with the highest power when participants' eyes were closed (Berger, 1929; Adrian & Matthews, 1934). When participants perform a task outside they are drawn to attend to their environment, while indoor experiments including the present study do not have this effect.

4.2 N1 and P2 components

The auditory N1 appears to reflect several functions, including an attentional function of sensory acceptance and rejection, which appears to amplify auditory perception of interesting, pleasant or important stimuli while attenuating the perception of uninteresting, unpleasant or unimportant stimuli (Näätänen & Picton, 1987; Roder et al., 1999). The N1 has been referred to as an early, rapid selection of competing auditory 'channels' or auditory inputs, defined by differing pitch or location cues (Hansen & Hillyard, 1988). For example, the N1 tends to be

increased when a sensory stimulus is located where one was already attending, and decreased when the same stimulus appears anywhere else, (Teder-Sälejärvi, et al. 1998). This is believed to allow enhanced processing of the stimuli of interest, and the effect is increased when the individuals performing the task are blind (Roder et al., 1999). The N1 component tends to have shorter latency and larger amplitude when the attended and unattended sounds are easily distinguishable by physical cues such as their pitch or location (Näätänen, 1982, 1992). This component has been shown to have increased amplitude as a function of increased attentional allocation to a specific input channel, as well as more accurate behavioural target detection for targets in that channel (Hink, Voorhis, Hillyard, & Smith, 1977). Functionally, the N1 amplitude and latency is believed to represent the amount of sensory information moving through an early mechanism of channel selection (Hillyard. Hink, Schwent, & Picton, 1973), further processing of information from the attended channel (Näätänen, 1982; Okita, 1981) as well as how well the eliciting stimulus and cue characteristics match within the attended input channel (Näätänen, 1992). In this study, it appears that the N1 increased when participants had to pay more attention and 'tune in' in order to perform the task properly in less than ideal conditions, and therefore was increased when *outdoor sounds* and *white noise* were played in the background, as well in the *silent-low* condition when the tones were simply quieter.

While the N1 has been shown to increase with increased attentiveness, the P2 has been shown to decrease to attended stimuli (Crowley & Colrain, 2004). The P2 has been found to reflect stimulus evaluation and classification as well as attentional allocation (Potts, 2004). For example, this component has been shown to decrease in response to speech sounds in a cocktail party task, while individuals had to pay attention to certain speech cues while ignoring simultaneous irrelevant speech sounds (Getzman, Golob & Wascher, 2016). This may be related

to a mechanism of how effectively stimuli are able to be discriminated, as several studies have shown that the auditory P2 increases in amplitude after discrimination training (Atienza, Cantero, Dominguez-Marin, 2002; Hayes, Warrier, Nicol, Zecker, Kraus, 2003; Reinke, He, Wang, Alain, 2003; Trainor, Shahin, Roberts, 2003; Tong, Melara & Rao, 2009; Tremblay, Kraus, Carrell & McGee, 1997; Tremblay & Kraus, 2003) as well as with simple exposure to the stimulus (Sheehan, McArthur & Bishop, 2005). In our study, playing a conflicting sound in the background may have decreased the participant's ability to discriminate the tones from background sounds in the traffic sounds and white noise conditions, causing a decrease in the P2. This may also explain why there was no P2 effect in the quiet tones condition, as the lower volume may have increased attention to the task, without decreasing the ability to discriminate the tones.

It appears that not only are both the N1 and P2 components affected by changes in one's sensory environment, they appear to serve separate functions and be differentially affected by changes to the task. Looking again at the plot of grand average ERPs to the standard tones in Figure 5B, the N1 appears to be altered from default value (e.g. amplitude in the silent condition) by any change that may alter one's attention to the task. In other words, as both of the background noise conditions and the *silent-low* condition would require the participant to 'tune-in' to the oddball tones in order to perform the task properly, all of these conditions caused an increase in the N1 component compared to the silent condition, with none of these conditions significantly differing from each other. Conversely, the P2 appears to only decrease to background sounds during the task, as only the *outdoor sounds* and *white noise* conditions had significantly smaller P2 amplitude than the *silent* condition. Further, this effect appears to be especially strong for salient and/or 'eventful' background stimuli, as the *outdoor sounds* had a

significantly smaller P2 amplitude than the *white noise* condition. As no behavioural differences were found, it appears that the N1 and P2 represent two separate but related processes that allow individuals to both hone-in on a relevant task, while tuning-out any extraneous and distracting sound in order to perform the task sufficiently in a noisy environment. These hypotheses require future investigations both inside and outside the lab.

4.3 Future Directions

With this new knowledge about the functions of the N1 and P2 components, we intend to investigate further into how these components relate to the way humans perform auditory and visual tasks in ecologically valid environments. This includes studies on the visual ERP when the task is performed with a visually noisy background, as well as cross modal studies in which an auditory task is used in a visually noisy environment, and vice versa. As well we plan to perform further outdoor studies in which auditory and visual tasks are performed in environments with differing auditory and visual noise. The main goal is to examine exactly how the human brain is able to compensate and perform tasks effectively in the face of distracting stimuli.

4.4 Conclusion

In this study, we replicated the effects found in a previous outdoor ERP study of decreased early sensory ERP components by only replaying the background sounds from the previous environment. Traffic sounds and white noise both modulated the N1 and P2 components of the ERPs evoked during an auditory oddball task. We found evidence that the N1 and P2, while functionally related, appear to perform two distinct mechanisms during stimulus discrimination in ecologically valid conditions. It appears that the N1 increases with attentiveness as one tunes in to a particular channel of auditory input, while the P2 decreases with attention and as the auditory channel becomes more difficult to discriminate. This effect

appears to be part of a mechanism that allows one to selectively attend to auditory tasks in noisy sound environments, like humans experience often in their day to day life.

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