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Considering a different point of view; The effect of stimulus distance and angle on the N170 as seen in scalp- and ear-EEG

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Abstract

Brain-computer interfaces can be improved by taking into account the effects of unstandardised environments on event-related potentials and by developing compact EEG devices. The face invoked N170 was used in this study to test the effects of distance and angle on peak-amplitude and -timing. This study also tested an EEG device placed in the ear to assure that an N170 was detectable in this ear-EEG data when referenced to a similar reference as the scalp-EEG and when referenced to its own reference. Wearing both scalp- and ear-EEG the participants were shown scrambled and non-scrambled faces which required different button presses. Five participants did this task in all three seating conditions: two metres away from the stimulus, 50 centimetres away and 50 centimetres away while seated at a 35 degrees angle with regards to the stimulus. Expected was that peak amplitude would decrease with distance and angle, and that peak timing would change only with angle. Amplitude decreased with distance and angle. Peak timing was unaffected by angle, but was affected by distance. The N170 was not distinguishable in ear-referenced ear-EEG data. Explanations were formulated for unexpected results. Although effect sizes were small to medium, future research is interesting to discover if the trend has a quadratic or linear nature and whether non-face stimuli which invoke an N170 follow a similar trend. If they do not follow this trend then face invoked N170 and non-face invoked N170 may become indistinguishable over distance and angle.

Keywords: Electroencephalography, EEG, scalp-EEG, ear-EEG, ear, BCI, Brain-Computer Interfaces, position, location, distance, angle, N170, amplitude, latency, timing, event-related potential, ERP

The brain is an intricate machine that has its own fields within science dedicated to discovering how exactly it works. Although none within these fields would claim we already know all there is to be known about the brain, some are certain we know enough to start working on applying this knowledge. A testament to which is the field of Brain-computer Interfaces (BCI) which is a sub-field of neuroscience focused on using information gathered from the brain to allow the brain to reach beyond its typical functions and control outside devices. When given time and proper use BCI could potentially develop into a revolution akin to cellular phones where everyone in the street will own one to control their own devices and the devices around them. Consider technologies like augmented reality glasses working in tandem with BCI to indicate to the user where to go because the user thought “I'm not quite sure how I can get back to the train station from here” or where thinking about a certain song will have the BCI send a signal to an earpiece which would then play that song.

Naturally this is future talk and research is still being done on how to best use BCI. Examples of this are Luhrs, Sorger, Goebel, and Esposito (2017) developing algorithms to deduce what letter the user is thinking about and others attempting to more accurately predict what movement with what part of the body the participant is making in the brain for use with the selection of items on a computer screen (Misawa, Matsuda, & Hirobayashi, 2017).

This is not to say that there are not already applications being developed which show what BCI is capable of as Hochberg et al. (2006) used it to allow a quadriplegic man to control a cursor on a computer screen and opening emails in addition to controlling a multi-jointed robotic arm. With some creativity BCI can also be employed to use the brain's original toolset in new ways. Kryger et al. (2017) allowed a quadriplegic woman to successfully execute different manoeuvrers in a flight simulator using the brain commands typically used to control prosthetics.

Unlike what may have unwittingly been suggested the field of BCI is indeed not so disjointed and secretive that one group would be researching how to recognise movement in the brain in 2017 while another group has allowed someone to control a flight simulator in the same year using similar techniques. Indeed this disparity is due to the neuroimaging methods used, as there are different techniques used to extract data from the brain. All else being equal it would seem straightforward to use the technique that allowed the user to control the robotic arm back in 2006, which is the same technique that was later used to allow control over the flight simulator. However all else is not equal as this technique requires the user to have electrodes placed on or even into the brain, which would restrict BCI to a very small and very dedicated user base. Instead the most commonly used technique is electroencephalography (EEG).

Electroencephalography

EEG is a technique which uses electrodes placed on the scalp to measure the release of electrical charges in the brain. These electrical charges are held by the neurons of the brain (Kalat, 2012) and are released when these neurons are activated. EEG was first used on humans by Hans Berger in 1924 (Jacks, & Miller, 2003) which indicates that it is a rather old tool. However, old as it may be it is still used in hospitals to aid with medical procedures (Quinonez, 1998). Similarly it is still an often employed neuroscientific tool. Typically when used in a scientific setting one of the senses of the participant is exposed to some manner of stimulus, after which the data gathered from the moments after this exposure is inspected for either pervasive waveforms within a certain frequency range or for spikes in amplitude occurring a predictable amount of time after stimulus exposure (the latter of which is referred to as an event-related potential or simply ERP).

EEG has a clear benefit over newer techniques, such as functional magnetic resonance imaging, which is the fact that the hardware required for EEG is small and moveable in addition to being relatively cheap. It is also known for its high temporal accuracy. It is because of these perks and their potential that EEG is popular for use with BCI but EEG does have its fair share of faults.

When used in a laboratory setting EEG suffers from noise in the data caused by the use of the muscles of the face. The blinking of the eye and the clenching of the jaw are two of such artefacts, but merely moving through the earth's magnetic field or being near other electrical devices will also add noise. Perhaps one of the most basal issues is that it also takes a considerable amount of time to prepare EEG to be used in addition to requiring the user to have electrode gel put in their hair and having them wear an aesthetically unappealing cap. Progress is being made towards resolving these issues with the development of new electrodes like the creation of dry active electrodes (Fonseca et al., 2007) which will reduce noise caused by outside sources and by movement of the cables in addition to obsoleting the use of electrode gel.

In order to test new electrodes or other such innovations one could invoke a well known ERP and compare its data which was gathered using the unmodified EEG device to the data gathered using the EEG device which has the new innovation implemented into it. De Lissa, Sörensen, Badcock, Thie, and McArthur (2015) use this principal in their article to successfully validate an EEG system built for use with videogames by inducing an N170 ERP.

N170

The N170 is an ERP that is likely generated in the occipitotemporal cortex (Allison, Puce, Spencer, & McCarthy, 1999). It responds to face stimuli with a strong negative peak roughly around 170 milliseconds after the face had been seen, although it is also known to respond to other images that represent something the viewer is experienced with (for example houses) albeit a bit weaker (Rossion, & Jacques, 2011). It has a counterpart called the vertex positive potential which is measured over the vertex as a positive peak roughly 170 milliseconds after the presentation of a face stimulus (Rossion, & Jacques, 2011). It is an easy to employ experimental paradigm which merely requires a participant to be exposed to greyscale images of a face shown on a black background to work (De Lissa et al., 2015). For this study the most important trait of the N170 is that it is strongest in an area near the ear (Rossion & Jacques, 2011) which means it could perhaps be detected by electrodes around- or even inside of the ear.

Ear-EEG

Because of the location of the N170 it could perhaps be detected by EEG devices that either go around the ear (Bleichner, & Debener, 2017) or inside the ear canal (Mikkelsen, Kappel, Mandic, & Kidmose, 2015), the latter of which being the device used in this study (see Figure 1). Immediately this indicates a downside of EEG devices with such limited coverage of the head as there may indeed be ERPs that are strongest outside of this coverage and so cannot be detected. Furthermore known ERPs may appear warped as the traditional detection location of the signal and the detection location with the new device may be on opposite sides of the ERP source, akin to how N170 is effectively an inverted vertex positive potential (Rossion, & Jacques, 2011). This effect may be enhanced for EEG devices placed inside the ear as this is a novel location for EEG measurement. However aside from the initial confusion that may be caused by this, no real problem exists as long as the warped ERP is as consistent as its known counterpart.

There are some definite reasons to use ear-EEG, among which are the reduced setup times,

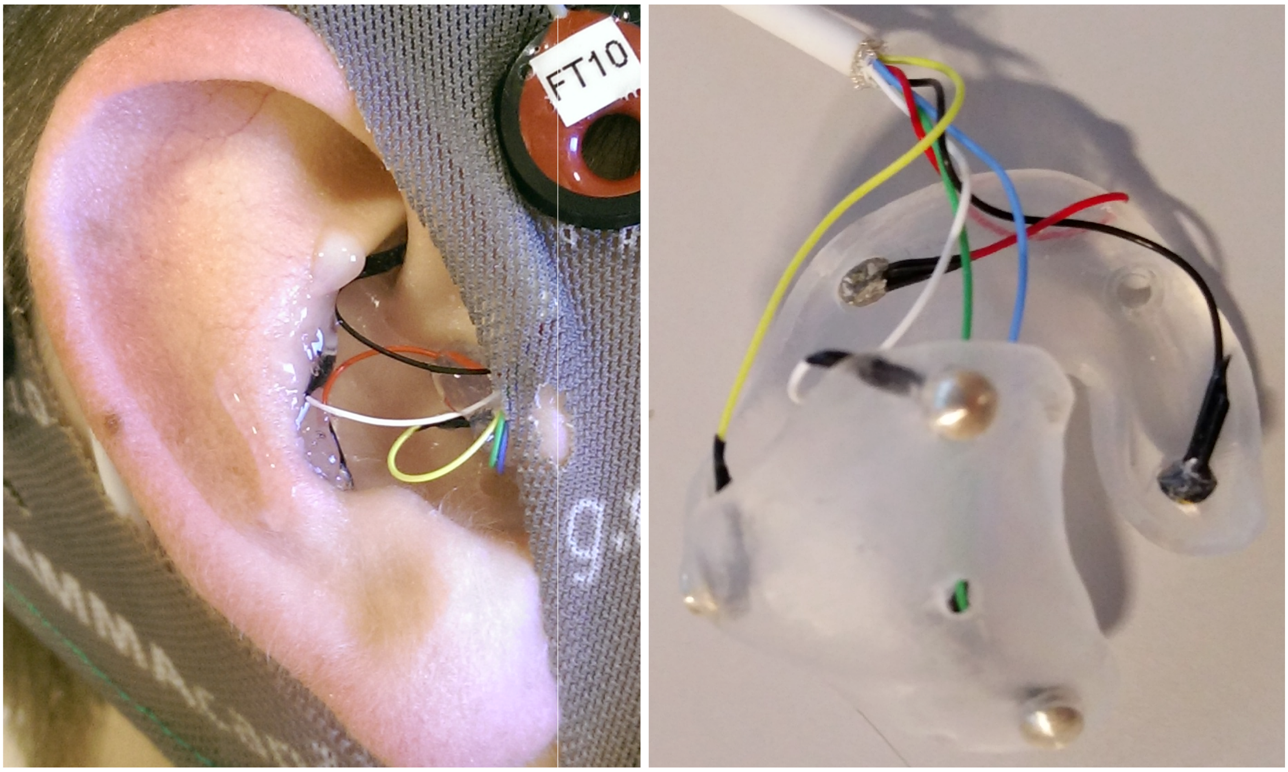

Figure 1: An image of ear-EEG inside and outside the ear

the relatively covert design and the potential to integrate them into existing devices such as hearing aids and headphones. Furthermore, although the version used in this study still required electrode gel, dry electrodes will work excellent with this device as the trait of it going into the ear allows the electrodes to make contact with the skin as long as they are put into a material that pushes outwards.

Integrating ear-EEG into existing devices that already go into the ear would be a low threshold way to introduce the general public to BCI. However, EEG has predominantly been used in the laboratory and so there are novel problems that need to be taken into account when taking BCI out of the laboratory.

Outside the laboratory

Ultimately it must be possible to use BCI outside of controlled settings such as the laboratory if it is to be used in applications that are to seriously and positively impact the lives of the users. Solutions to problems that occur in laboratory settings may not be feasible outside of this setting. Minguillon, Angel Lopez-Gordo, and Pelayo (2017) describe how the noise in the data caused by consistent motion, a problem that can be solved in the laboratory by simply asking the participant not to move, will have to be removed from the data using new methods. However entirely new problems may arise as the uncontrolled environment of the world outside of the laboratory may alter how relevant stimuli are perceived. New problems may find their cause in physical differences, where less illuminated cloudy days make the target stimulus look darker than it looks on bright sunny days, as well as psychological differences, where the user may be distracted by car horns or ambient chatter.

There are several studies that have shown that the size of a stimulus impacts the EEG signal: De Cesarei and Codispoti (2006) showed in their experiment that affective modulation is reduced in smaller compared to larger stimuli; a study done by Busch, Debener, Kranczioch, Engel, and Herrmann (2004) found that gamma band response amplitude is affected by stimulus size, and that visual evoked potentials have their phase, which is to say the timing of the peak, affected by laterally placing a stimulus; and a study done by Pfabigan, Sailer, and Lamm (2015) revealed that smaller stimuli lead to diminished amplitudes in FRN and P300 components relative to middle or large stimuli sizes. An actual considerable change in the size of the target stimulus in the world outside of the laboratory is typically not a common occurrence. However, size is used in depth perception (Wandell, 1995) in so far that the brain estimates the distance between an object and the perceiver based on the knowledge of how big the object is and based on the space occupied by this object on the retina. Armed with this knowledge one could assert that size is a proxy for distance and therefore that distance would have a similar effect on EEG data as size has. This assertion was put to the test in the current study.

The Busch et al. (2004) have also shown that when the participant was fixated on a cross in the middle of a screen, the presentation of a stimulus slightly to the side of this cross also affected the phase of a visual evoked potential. When allowing for conjecture one could say that perhaps this is caused by slower processing of stimuli presented in the peripheral visual field. However, more relevant for this particular experiment is the notion that perhaps seeing the features of the image at an angle distorts them slightly compared to when seeing them from the front. Picture a perfect cube when seen straight ahead and when seen at an angle; when seen at an angle it may be seen as a trapezium as the side further away may appear smaller than the side closer to the viewer. This latter situation is worth investigating as it is possible that when using BCI in the outside world the target stimulus may not always be presented straight in front of the user. Additionally, when using the N170 for the experiment the small distortion of the features of a face image caused by the angle could bring the amplitude of the face image ERP closer to the amplitude of a non face image ERP. As mentioned before non face images can still elicit an N170, but it will be smaller in amplitude than an N170 caused by a face image (Rossion, & Jacques, 2011).

Current study

This study aims to discover if the N170 can be seen in electrodes placed in the ear when referenced to the same electrode as the scalp and, if so, if this is still possible after these electrodes have been referenced to a reference electrode in the ear. Furthermore it is also intended to reveal whether or not position influences the ERP and, if so, how.

In order to answer the latter question for the electrodes of both EEG devices, the former must be answered first. This was done by exposing participants outfitted with both ear- and scalp-EEG simultaneously to greyscaled images of faces from three different positions: nearby, far away and at an angle. The position was key to answering the second research question, but the first could be answered with just the data from the near condition. The first two hypotheses tested were: “The face stimulus N170 can be detected in data acquired using any of the scalp-referenced ear-EEG electrodes and is significantly different from non face stimulus N170”; and “The face stimulus N170 can be detected in data acquired using any of the ear-referenced ear-EEG electrodes and is significantly different from non face stimulus N170” where ELT is the reference for the left ear and ERT is the reference for the right ear. Both of which are placed on the tragus of the respective ear.

The nearby, far and at an angle positions were chosen to represent different aspects of positioning and lead to the following hypotheses: “The amplitude of the N170 decreases with distance to the stimulus”; “The peak timing of the N170 increases when the participant is viewing the stimulus at an angle”; and “The amplitude of the N170 decreases when the participant is viewing the screen at an angle”. These hypotheses are tested separately for amplitude and peak timing due to the fact that the correlation between these two variables was too low to justify a MANOVA. This causes a multiple comparison problem and so a Bonferroni corrected significance threshold was used.

Materials and Methods

Design

This study used a 2x3x5 within subject design where all participants went through all conditions, which consisted of the nominal independent stimulus variable (scrambled face, face), the nominal independent position variable (near, angled, far) and a final nominal independent electrode variable (P7, P8, ERB, ERC, ERG). The two dependent variables of interest were the average peak amplitude measured at ratio level, and the average peak timing measured at interval level. For the analysis the data of all participants in the position and electrode conditions were compared to the data of all participants in the position and electrode conditions. Additionally attention was also paid to the interaction effect of these two conditions to find out if position impacted the signal of different electrodes differently. In order to make sure there was no effect of presentation order, randomisation was used on the images, image sets and locations, this is further elaborated on in the stimuli and procedure section.

Consideration must also be given to additional possible interpretations of the results. The biggest factor that could lead to additional interpretations was the movement of the screen and the shift of the visual focal point and peripheral vision that comes with it. The area around the participant that could be seen by the participant was different between conditions due to the inherent reflectiveness of the screen combined with the change in position of the screen. But the things that could be seen in the same position across participants was never vastly different as the items around the participant were always the same, with no brightly coloured or moving objects or people that could distract.

The stimulus (scrambled face, face) variable was only used for comparing the averaged scalp electrodes N170 difference waves to the averaged ear electrodes N170 difference waves when referenced to the same electrode as the scalp. This was done in order to test if there was a difference between the N170 as seen on the scalp as compared to the N170 seen in the ear and so to test the hypothesis that the N170 was indeed similar and detectable in data gathered using ear-EEG. Difference waves were used rather than the raw N170 itself to compensate for the naturally diminished amplitudes that are seen in the ear. The rest of the study concerned the effect of changes in position on the signal of the electrodes and whether this effect differed in different electrodes.

Participants

This experiment employed five participants who were all affiliated with Aarhus University as either a teacher or a student. Of these five participants four were male. The mean age was 31.4 with a standard deviation of 8.2. The oldest participant was 44 and the youngest 22. All participants had normal or corrected-to-normal vision. The participants were pre-selected on the basis of already having a custom made ear-EEG device, after which an email was sent directly to them to ask for their cooperation. No alterations to these devices were made that could reasonably be thought to have made these devices any less safe compared to when the participants first used these. None of the participants dropped out. The participants were not compensated for their participation. All participants gave their informed and written consent to participate in this study in line with the regulations put in place by Aarhus University.

Stimuli and procedure

After signing the informed consent at the Aarhus University laboratory the participant was prepared for ear-EEG. This was done by first cleaning the concha, tragus and ear canal using alcohol followed by abrading these same areas using exfoliation gel. The electrodes of the ear-EEG were then covered in a thick conductive paste to create a good connection between the skin and the electrode. If regardless of this the impedance was still unacceptable, then electrode gel, which is commonly used for scalp-EEG that relies on wet electrodes, was applied under the ear-EEG electrodes. After also putting on the electrode cap the experiment started.

First the participant was presented with an instruction screen which informed the participant to always look at the notch in the centre of the screen, which would be replaced with an image of either a face (target stimulus) or of a scrambled face (neutral stimulus), this would then be replaced

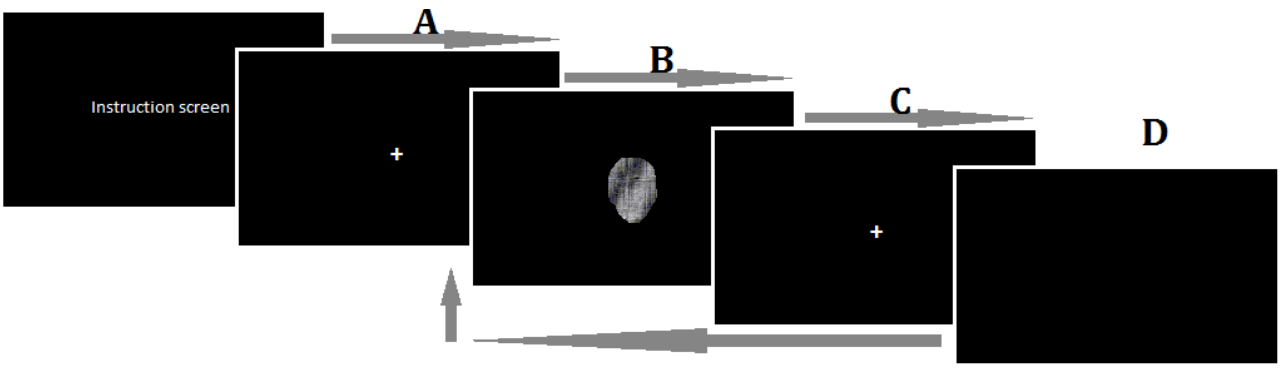

Figure 2. The sequence of screens that was shown to the participant. The instruction screen stayed until a key was pressed. Screen A appeared for 500 milliseconds. Screen B appeared for 200 milliseconds. Screen C and screen D appeared for 1000 milliseconds. While screen D was seen the participant was allowed to blink and tasked with pressing a button on their left if they had seen a face, or a button on their right if they had seen a scrambled face. After screen D the sequence started anew with a different image shown on screen B, which would randomly be a scrambled- or normal face.

by a notch once more, which would then disappear. During this period where there was nothing on screen the participant was allowed to blink, and was tasked with pressing a button on their left if the image had been of a face, and on their right if the image had been of a scrambled face. This sequence can be seen in Figure 2. Typically, asking the participant to blink during the same time interval as they are tasked to give a response would be ill advised due to the fact that the blink artefact would consistently eclipse any possible ERP caused by the response. However, data from this time interval is irrelevant to this experiment and the buttons were not connected to anything. This task existed only to incentivize the participant to keep paying attention. The participants were unaware these buttons were not connected. After seeing 180 images, the participant would be allowed to take a break as the next condition was being prepared.

In total there were three conditions; near, far and angled. These respectively meant the stimulus would be placed straight in front and at a distance of 50 centimetres away from the participant, straight in front and at two meters away from the participant, and at 50 centimetres away at a 35 degrees angle. Due to the fact that the distance was relative to the stimulus, and not to the screen the stimulus was displayed on, the screen was closer to the participant in the angled than in the near condition, as can be seen in Figure 3. After the participant was done with all three conditions which all had the same instructions, and after the EEG had been removed from their head, about 90 minutes would have passed with every separate condition having taken up 8 minutes.

The three conditions were accompanied by three different image sets which consisted of 90 greyscaled images of famous people and their 90 scrambled face counterparts, all of which were 128 x 162 pixels in size. Due to having a limited number of images which could be shown, different

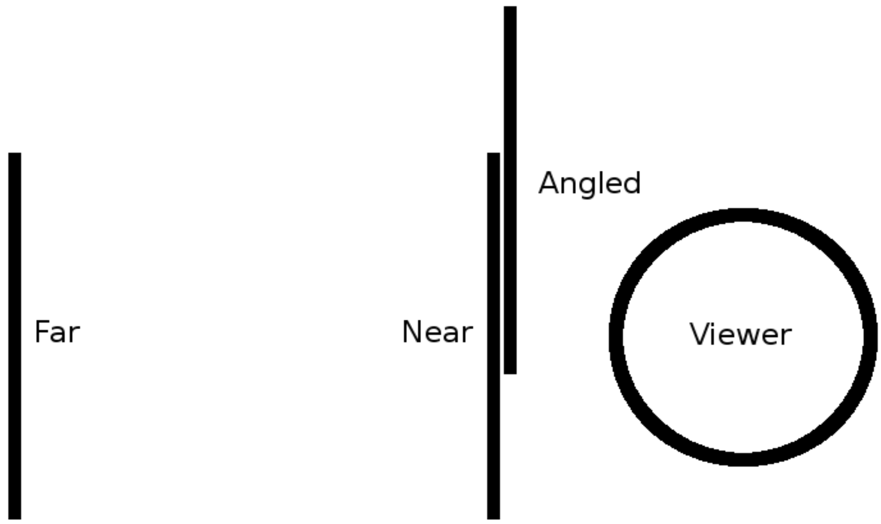

Figure 3: A clarification of the different positions. Note how Angled is slightly closer to the face than Near. This is due to the fact that the distance was taken between the participant and the stimulus, not between the participant and the media on which the stimulus was presented. Image not to scale.

image sets had some images in common. This resulted in the first image set only containing new images, the second having half of the images be new and half be seen before and the third having no new images. This was compensated for by randomising the order in which the image sets were shown on top of randomising the order in which the participant sat through the different conditions. Additionally, the presentation order of the images within the current image set was also randomised.

ERP recording and data analysis

This experiment used 32 scalp electrodes (Fz, Fcz, F7, F8, FC3, FC4, FC5, FC6, FT7, FT8, C1, C2, C3, C4, C5, C6, T7, T8, CP3, CP4, CP5, CP6, TP4, TP8, TP9, TP10, P3, P4, P5, P6, P8, P7) in accordance with the international 10-20 system. Additionally; 2x6 ear electrodes were used. ELA, ELB (both left ear), ERA and ERB (both right ear) were placed inside of the ear canal; ELT and ERT were placed on the tragus to be later used as a reference for offline re-referencing; ELC, ELG, ELK, ERC, ERG and ERK were placed in various places around the concha. Both scalp- and ear-EEG were online referenced to an electrode placed on the cheek.

Data was filtered using a 1.5Hz high pass filter and a 30Hz low pass filter. Epochs were drawn from -100 milliseconds prior to stimulus presentation up to 500 milliseconds post stimulus presentation. One scrambled face epoch was rejected because the data in this epoch had been recorded too soon after starting the experiment, causing the signal to go far out of bounds. The N170 peak was identified within the remaining epochs using an algorithm that looked for the minimum amplitude within the time-range of 100 and 240 milliseconds after stimulus presentation in each trial. After this had been found, the algorithm would first make sure this was the lowest possible point in the peak, after which it identified the slope on the left and the right side of this point by using a stepwise comparison where it would compare the amplitude of the current datapoint to that of the previous datapoint, and doing this until the previous datapoint had a larger amplitude value than the current datapoint. If the previous datapoint had a larger amplitude value than the current point this meant the current datapoint is at the beginning or the end of a different peak.

For the datapoints at the beginning and the end of the peak the time post stimulus presentation was also registered. This was added together and divided by two to get an average peak timing. Similarly, the amplitudes of all the data points in the peak were averaged to get an average peak amplitude.

Due to an extremely low correlation between the dependent variables (r = -0.003); rather than doing a single repeated measures MANOVA two repeated measures ANOVAs using electrode and location as within subject variables were done with one testing the effect on amplitude and the other testing the effect on peak timing. Both electrode and location used simple contrasts with electrode comparing all signals to the scalp electrode P8 and position comparing angled to near and far to near. The results from these repeated measures ANOVAs were used to test the validity of all hypotheses that involved the effect of location on the N170 in different electrodes as the contrasts would indicate significant differences between electrodes, between positions and between positions when looking at them through different electrodes. For both repeated measures ANOVAs the assumptions of normality, a lack of extreme outliers and sphericity were checked. The results of these checks and the implications of the results are documented in the 'Assumptions' paragraph of the results sections.

The hypotheses which claimed that the N170 can be seen in ear-EEG when referenced to the scalp reference or to its own ear reference are tested preliminary at the start of the results section. This is due to the fact that the knowledge of whether or not this hypothesis holds true was required for the selection of the electrodes placed in the ear that were to be further analysed for its susceptibility to location changes. Testing this hypothesis was done using a cluster permutation which means a t-test was done on every individual datapoint in the entire EEG waveform, after which the different 'islands' of significant datapoints were identified. These 'islands' themselves cannot reliably be used as an indication of actual significance as at this point such a large amount of t-tests has been done that one would almost always find a significance somewhere (the multiple comparisons problem). The cluster permutation works around this problem by identifying the 'island' with the largest sum t value after which, under the assumption that if the face N170 and the scrambled face N170 are the same it does not matter from which you draw data, it creates several thousand different datasets by randomly switching out data from the face set with the scrambled face set. This created a normal curve of sum t scores to which the actual observed sum t scores of all separate 'islands' were compared and which then gave p values for all these 'islands' (For further reading see: Ernst, 2004; Maris, & Oostenveld, 2007.). The cluster permutation is a nonparametric test which implies there are no assumptions.

Software and Apparatus

The experiment was made and ran using the Psychtoolbox plugin for MathWork's Matlab, recorded using G.recorder and processed using the EEGLab plugin for MathWork's Matlab after which it was analysed using IBM SPSS Statistics. The used hardware included a G-tec amplifier, 32 channel electrode cap and electrode driver box. Additionally a G.TRIGbox, custom made 2x6 channel ear-EEG, and a non-crt television screen as well as common items like personal computers, a chair and buttons were used. The images had been shown to evoke an N170 in preliminary experiments done in the lab at Aarhus University as well as being a relatively standard kind of N170 stimulus.

Channel selection

As the N170 is typically maximal at P7 and P8 (as seen in: Kloth, Itier, & Schweinberger, 2013; O'Toole, DeCicco, Berthod, & Dennis, 2013; Johnston, Molyneux, & Young, 2014) only these scalp electrodes were used for the analysis. Ear electrodes were selected based on whether or not a significant difference could be found between the face and scrambled face conditions around 170 milliseconds post stimulus presentation in the near condition. The near condition was used as it most closely resembled the position used in other N170 experiments where position is not a factor, as well as being the location where the difference between face stimulus and neutral stimulus was most likely to be the largest. The aforementioned significance was checked for using a two-sided cluster permutation and was followed up on with a visual inspection to make sure there was indeed a scalp-EEG like peak around 170 milliseconds in the face stimulus condition waveform.

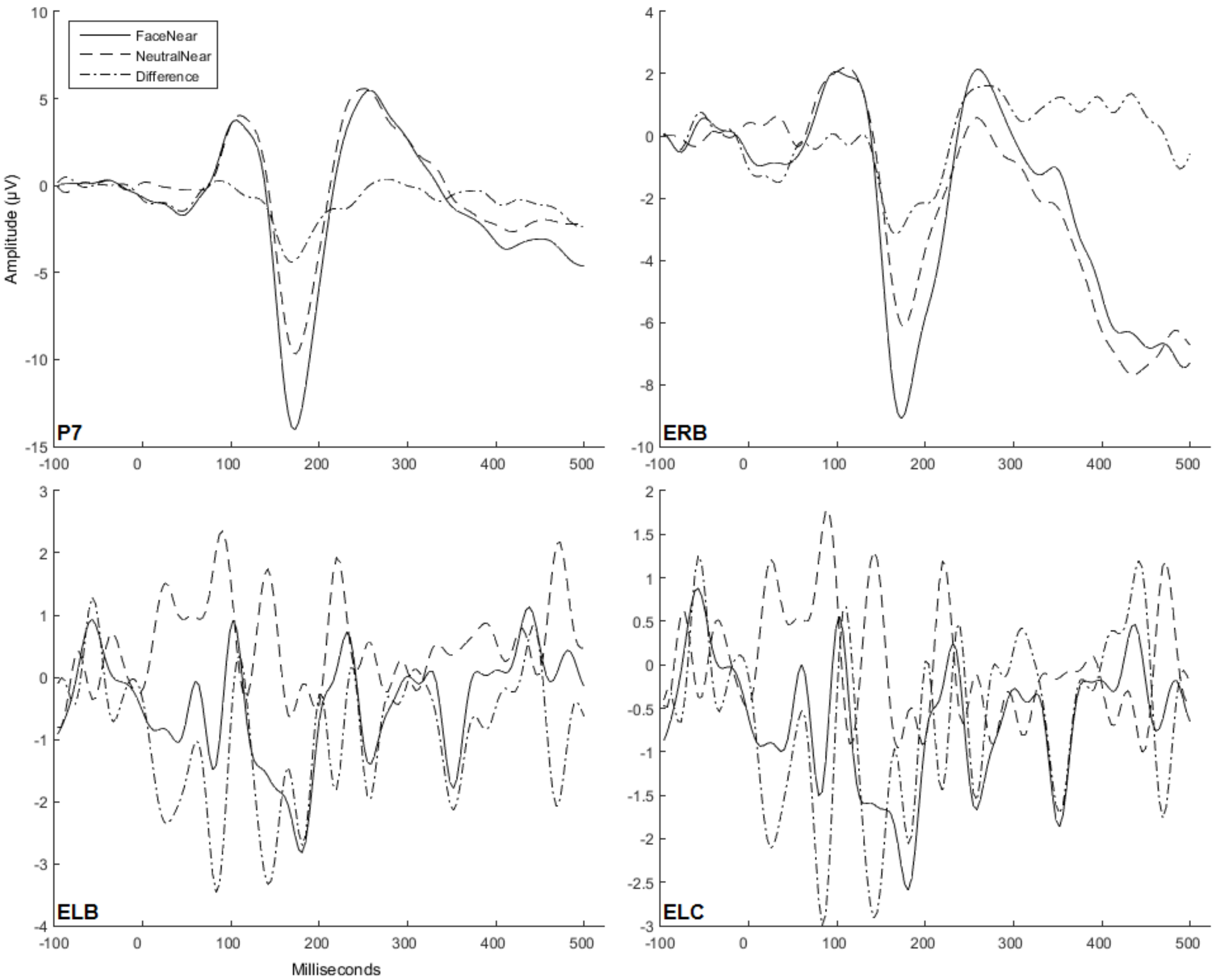

Figure 4: The near condition N170 as seen in some of the electrodes. P7 and ERB are referenced to the scalp whereas ELB and ELC are referenced to the left ear. The full line indicates data from the face stimuli condition, the dashed line indicates data from the neutral (scrambled face) condition and the dashed dotted line is the difference between these two. Note how the amplitude differs between plots. Note also the peak around 150 milliseconds in the difference wave in the ELB and ELC conditions

Results

When referenced to the scalp reference the N170 peak was found in ERB ($p < 0.025$), ERC ($p < 0.05$) and ERG ($p < 0.01$). When referenced to the ELT for left ear and ERT for the right ear the N170 peak was found in ELB ($p < 0.01$) and ELC ($p < 0.025$). These latter two significances were found around 150 milliseconds post stimulus, which has some sort of extrusion which flows into the N170 peak in the face stimulus data, but which has a very distinct separate peak in the difference wave (See Figure 4). The difference wave peak around 170 milliseconds was significant in neither ELB nor ELC. Additionally, a second cluster permutation was done to see if there was a significant difference between the signal found in P7 and P8 in the near condition, and the signal in the scalp referenced ERB, ERC and ERG in the near condition. This was done by taking the difference wave of the averaged P7 and P8 face stimulus wave and their neutral stimulus waves and using the cluster permutation to compare this to the difference wave of the similarly averaged ERB, ERC and ERG channels. The difference wave, rather than merely the face condition signal, was used in order to nullify any possible structural amplitudinal differences between ear electrodes and scalp electrodes. This analysis showed no significant difference between the two channel sets at about 170 milliseconds.

The results of the assumptions check and its implications shall be discussed first. Afterwards the effect of the independent variables on amplitude shall be presented, followed by the effect of the independent variables on peak timing. To counter the multiple comparison problem brought about by separately analysing both dependent variables, but at the cost of some statistical power, the results are compared to a Bonferroni corrected significance level, which in this case is 0.025.

Assumptions

Through the use of Q-Q plots it was determined that both the variables amplitude and peak timing were roughly normally distributed in all locations. Cases that had a z-score above an absolute value of 3.29 were marked as outliers and then removed. Upon removal of these outliers 420 out of 450 cases remained for every electrode and position combination when considering amplitude and 431 out of 450 cases remained for every electrode and position combination when considering peak timing.

When looking at amplitude Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of electrode $X^2(9) = 1252.43$, $p < .001$, and the interaction effect of electrode and position $X^2(35) = 1009.14$, $p < .001$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .43$ for the main effect of electrode and .63 for the interaction effect of electrode and position). Mauchley's test indicated that the assumption of sphericity had been met for the main effect of position, $X^2(2) = .89$, $p = .642$.

When looking at peak timing Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of electrode $X^2(9) = 457.02$, $p < .001$, and the interaction effect of electrode and position $X^2(35) = 970.69$, $p < .001$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity($\varepsilon = .70$ for the main effect of electrode and .65 for the interaction effect of electrode and position). Mauchley's test indicated that the assumption of sphericity had been met for the main effect of position, $X^2(2) = 1.52$, $p = .469$.

Amplitude

There was a significant main effect of the electrode used on the amplitude of the N170, $F(1.72, 719.74) = 9.51$, $p < .001$, $\eta^2_{partial} = .02$. Contrasts revealed that P7 does not differ significantly from P8, $F(1, 419) = .01$, $p = .905$, $\eta^2_{partial} = .00$. The remaining contrasts showed that the amplitudes in ERG, $F(1, 419) = 36.74$, $p < .001$, $\eta^2_{partial} = .08$ ERB, $F(1, 419) = 17.73$, $p < .001$, $\eta^2_{partial} = .04$, and ERC, $F(1, 419) = 32.59$, $p < .001$, $\eta^2_{partial} = .07$, were significantly closer to zero (smaller) than in P8. Descriptive statistics for the electrodes can be found in Table 1.

Table 1. *Electrode descriptive statistics*

				95% Confidence Interval	
Electrode	Mean amplitude	Std. Error	Std. Deviation	Lower Bound	Upper Bound
P8	-4.32	.27	9.55	-4.85	-3.79
P7	-4.26	.36	12.81	-4.97	-3.55
ERG	-2.68	.28	10.05	-3.24	-2.12
ERB	-3.22	.28	10.05	-3.78	-2.67
ERC	-2.76	.28	9.97	-3.31	-2.20

There was a significant main effect of the position from which the stimulus was seen on the amplitude of the N170, $F(2, 838) = 16.20$, $p < .001$, $\eta^2_{partial} = .04$. Contrasts revealed that the amplitude was significantly closer to zero in both angle when compared to near, $F(1, 419) = 18.98$, $p < .001$, $\eta^2_{partial} = .04$, and far when compared to near, $F(1, 419) = 29.75$, $p < .001$, $\eta^2_{partial} = .07$. Descriptive statistics for the positions can be found in Table 2.

Table 2. *Position descriptive statistics*

				95% Confidence Interval	
Position	Mean amplitude	Std. Error	Std. Deviation	Lower Bound	Upper Bound
Angle	-2.98	.32	11.36	-3.61	-2.35
Far	-2.55	.29	10.26	-3.11	-1.98
Near	-4.81	.31	11.11	-5.42	-4.20

There was no significant interaction effect of electrode and position, $F(5.01, 2098.7) = 1.94$, $p = .085$, $\eta^2_{partial} = .01$.

Peak timing

There was a significant main effect of the electrode used on the peak timing of the N170, $F(2.78, 1195.78) = 4.29$, $p = .006$, $\eta^2_{partial} = .01$. Contrasts revealed that P7 does not differ significantly from P8, $F(1, 430) = .95$, $p = .329$, $\eta^2_{partial} = .00$. The remaining contrasts showed that the peak timing in ERG, $F(1, 430) = 7.74$, $p = .006$, $\eta^2_{partial} = .02$, ERB, $F(1, 430) = 13.68$, $p < .001$, $\eta^2_{partial} = .03$, and ERC, $F(1, 430) = 8.59$, $p = .004$, $\eta^2_{partial} = .02$, were significantly delayed compared to P8. Descriptive statistics for the electrodes can be found in Table 3.

Table 3. *Electrode descriptive statistics*

				95% Confidence Interval	
Electrode	Mean peak timing	Std. Error	Std. Deviation	Lower Bound	Upper Bound
P8	172.94	.72	25.89	171.53	174.36
P7	173.92	.65	23.41	172.64	175.20
ERG	175.36	.81	28.95	173.78	176.94
ERB	175.85	.79	28.44	174.30	177.40
ERC	175.41	.79	28.23	173.87	176.95

There was a significant main effect of the position from which the stimulus was seen on the peak timing of the N170, $F(2, 860) = 16.60$, $p < .001$, $\eta^2_{partial} = .04$. Contrasts revealed that the peak timing did not differ significantly between the near and angled positions, $F(1, 430) = .36$, $p = .548$, $\eta^2_{partial} = .00$, but was delayed in far as compared to near, $F(1, 430) = 28.52$, $p = < .001$, $\eta^2_{partial} = .06$. Descriptive statistics for the positions can be found in Table 4.

Table 4. *Position descriptive statistics*

				95% Confidence Interval	
Position	Mean peak timing	Std. Error	Std. Deviation	Lower Bound	Upper Bound
Angle	173.10	.86	30.82	171.41	174.78
Far	178.59	.89	31.90	176.85	180.34
Near	172.40	.86	30.74	170.72	174.08

There was no significant interaction effect of electrode and peak timing, $F(5.22, 2243.55) = .41$, $p = .847$, $\eta^2_{partial} = .00$.

Discussion

The goal of this study was to test the effect of position on both latency and amplitude, as well as discovering the feasibility of ear-EEG when used for N170 when it was referenced to a similar reference as the scalp, and when it was referenced to one of its own reference electrodes.

N170 in the ear

The first hypothesis of this study was: “The face stimulus N170 can be detected in data acquired using any of the scalp-referenced ear-EEG electrodes and is significantly different from non face stimulus N170”. And indeed, when referenced to the cheekbone the ERB, ERC and ERG electrodes of the right ear showed an N170 which was significantly different when invoked by a face than when invoked by a scrambled face. Furthermore additional analysis showed no significant difference in the averaged difference wave N170 in the two scalp electrodes compared to the set of selected right ear electrodes, which implies these sets of electrodes are functionally identical when both are referenced to the cheekbone and when used in the near condition. None of the electrodes in the left ear showed a significant N170 result.

The second hypothesis was similar to the first, but the key difference was that the ear electrodes would now be referenced to their own ear references, ELT for the left ear and ERT for the right ear. Under this condition ELB and ELC both showed a significant difference at around 150 milliseconds post stimulus presentation. Further visual inspection showed that this significant peak was unlikely to be the N170. The idea that this was unlikely to be the N170 is further enforced by the fact that the previously significant ERB, ERC and ERG were not significant when using the ear reference. Taking all this into consideration it becomes apparent that the second hypothesis “The face stimulus N170 can be detected in data acquired using any of the ear-referenced ear-EEG electrodes and is significantly different from non face stimulus N170” is false. This means the N170 cannot be distinguished in ear-referenced ear-EEG data. Still, it cannot be ignored that in the ELB and ELC graphs of Figure 4 there is quite clearly a negative peak around 170 milliseconds in the face stimulus graph. However the amount and amplitude of other peaks in this data is indeed so large that it would be difficult for someone to tell what kind of ERP they are looking at if they were not explicitly told it is an N170.

The reason why there was no significant N170 in the left ear when referenced to the scalp-reference could be explained by the fact that the P8 showed a stronger mean amplitude in the near condition than the P7 in the near condition and so the N170 was stronger over the right side of the head than over the left side of the head. This stronger N170 in P8 than in P7 is also seen in other articles (Zhang, Wan, Luo, & Luo, 2012) so it may very well be the case that the left ear is simply not a good location for collecting N170 data. Additionally, the reason why the electrodes of the right ear no longer showed a significant N170 after re-referencing to the tragus could be the close proximity of the tragus to the electrodes of interest. This close proximity means that the re-

referencing filtered out much of the relevant data and so other ear-references may have to be developed.

The effect of distance on N170

One of the hypotheses of this study was that an increase in distance meant a decrease in amplitude. This was indeed the case for both scalp electrodes and for the three electrodes in the right ear when referenced to the same reference as the scalp. Additionally, the effect sizes indicated an effect which was around medium in size. This decrease in amplitude was in accordance with the results found in the Pfabigan, Sailer, and Lamm (2015), Busch et al. (2004), and De Cesarei and Codispoti (2006) studies. Furthermore these findings also support the claim that size is effectively a proxy for distance. However based on just the evidence presented in this study it would be remiss to take this as a fact as the change in amplitude caused by both distance and size may have different underlying processes which affect the data in a similar way. After all, the data only shows a peak that is made up from other peaks. If in an imaginary situation the shown peak was made from 2 perfectly overlapping peaks, distance could shrink one peak and size could shrink both peaks to a smaller extend, causing the end result to look the same while the underlying processes are affected differently.

An unexpected additional finding was that viewing a stimulus from a distance significantly delays the timing of the peak in all tested scalp-reference referenced electrodes while also having a medium effect size. It is possible that this effect is caused by additional environmental distractors drawing away attention. When the screen is placed further away, the visual field of focus will take up a relatively larger space of the surface of the screen and may then include more reflections seen in the screen. Additionally, less of the peripheral vision is occupied by the screen and now consists of more items found in the world around the screen that may draw attention away. However, these items that could be seen in either the reflection or peripheral vision are inert and the brain would likely quickly habituate to these items. Perhaps the explanation is as simple as it merely taking a little longer to recognise the face as being a face due to the features appearing to be smaller and therefore harder to perceive.

Although the theoretical underpinnings of this unexpected find may be interesting to wonder about, it has few directly practical implications for brain computer interfaces. The differences in means are so much smaller than the standard deviations that an algorithm build to detect the N170 in aggregate or even single trial data recorded from close to the target would likely have little trouble detecting the N170s in data gathered from participants who saw the target stimulus from further away.

The effect of angle on N170

Two hypotheses were formulated with regards to the effect angle would have on the N170 data. The first of which predicted an increase in peak timing when viewing the stimulus at an angle rather than straight on. This was not the case for any of the electrodes referenced to the cheek, including the ones in the right ear. And so the hypothesis that viewing a face at an angle will delay peak timing was proven false for all electrodes. At first glance this lack of effect of angle on peak timing may seem disjointed with the literature, but it just serves to show that the changed peak timing in the Busch et al. (2004) article was indeed more likely to have been caused by the effect of the stimulus having been presented in the peripheral visual field than the effect of seeing the stimulus at an angle. Additionally, participants were required to shift their focus away from the visual focal point in the Busch et al. (2004) experiment, but this was not done by the participants in the study described in this thesis. This shift of attention may be an extra step which could delay the start of the stimulus processing.

The second hypothesis, which included the effect of viewing angle, speculated that viewing angle would decrease the amplitude of the N170. This was the case in all scalp-reference referenced electrodes. Albeit with a small to medium effect size. An explanation for this effect could be that seeing a face at an angle in a real life setting would mean there is no social contact going on at this moment as the other person is simply passing you by, and that the face is therefore not important. Similarly, when speaking to someone at an angle this person would under normal circumstances turn their head towards you and so this effect would not be seen. This explanation leans on the idea that the amplitude of the N170 reflects the importance of the stimulus to the viewer, which may be backed up by the finding of Blau, Maurer, Tottenham and McCandliss (2007) who have shown that fearful faces elicit a stronger N170 than neutral faces do.

Limitations

Mind that these results are scarcely generalizable, as the amount of used cases may be confused for a large number of participants. In reality the number of participants was very small with a mere five, including only one woman and drawing a sample from a very specific group of people, namely engineering students. Additionally; two of these participants were heavily involved in the creation of this experiment, as one was the student who designed and executed it, and the other was his supervisor. Although this is poor practice, this was due to the ear pieces being custom made, and there not being enough time to look for participants who wanted to get one made and then also making it. A somewhat redeeming factor may be that automated responses like the N170 are likely to be immune to any potential top-down effects of knowledge of the experimental setup and the exact goal. However it is still an unnecessary risk that needs to be avoided.

Furthermore this study could be improved upon by making sure every face image in the different conditions is unique, rather than having duplicates. Although it may not affect the N170 much, it is much more elegant and casts away any shadow of doubt about the possible effect of duplicates on the N170. One could also choose to use a less face-like neutral stimulus. The choice to use the scrambled faces was a very deliberate one as the outline is the same, and the faces are scrambled in such a way that, although the features are unrecognisable, the way the shades of grey flow into each other is in keeping with the contrasts seen inside the face it was based on. This is to make sure the only difference between the stimuli is that one is recognised as a face and the other is not, but this does not make for a very accurate reflection of a neutral stimulus one would run into out in the real world and may have come at the cost of not including some ear-EEG channels which would have otherwise shown a significant difference between stimulus and neutral stimulus. Frontal images of watches could be a good alternative as the watch 'face' is round-ish and can be scaled to take up roughly as much space as a face.

It was also the case that the analysis consistently showed there was a significant difference between the scalp electrode P8 and the ear electrodes, even though the analysis using a cluster permutation showed the opposite. These two findings are not mutually exclusive as the cluster permutation used the difference waves precisely because there was expected to be a consistent difference in the raw amplitudes but not in the relative differences. Furthermore this difference in amplitude and peak timing in different electrodes influenced the effects of position on neither peak timing nor amplitude, as can be seen by the fact that the interaction effects were never significant.

Lastly, as was mentioned the delay in peak timing which was seen when the stimulus was seen from a distance was substantially larger than the difference in means and so this may have more theoretical implications than practical implications. One could reason that this is also the case for amplitude as the standard deviations are likewise much larger than the differences between means. However a trait which amplitude arguably does not share with peak timing is that it has limited working room in so far that the mean amplitude can start approaching the point where it becomes indistinguishable from the N170 evoked by a neutral stimulus. Peak timing does not have such a clearly defined point of when it is no longer workable. Even though individual cases may not be attributable to a specific position, the effect of position on amplitude may still be important for aggregate data and applications of this data.

Future work

Since, as far as the author is aware, this is the first time that the effect of position on ERP signals is measured the findings must first be confirmed by other research to be of any practical use. However based on what was seen some interesting other matters could be researched as well. First off it may be possible to get more insight into the inner workings of the brain by discovering if, assuming size can indeed be used as a proxy, the change in amplitude is only seen for size or distal differences in objects we are familiar with and of which the size is known. If this were indeed the case then it may be an indication of early processing with regards to target prioritisation in the real world. It could indicate that objects which are closer to the viewer, or objects that are abnormally large and perhaps more threatening than usual are more important to the brain. Although it could simply be the case that distance, just as size, makes faces look more like non-faces due to a loss of detail. A good start may be to test whether or not this effect is also present in other ERPs aside from just the N170. One could also look at other modalities to find out if a same effect is present for sound that is perceived to be more distal.

Another issue that was raised was that of possible effects of peripheral noise and reflections in the screen at the vocal point on the ERP as this may have caused the change in peak timing in the far condition. Peripheral noise is quite clearly an issue when taking EEG out of the laboratory and into environments crowded with potential distractors and so researching its effects on ERPs would certainly not be remiss. Vocal point reflections will be much less common in naturalistic settings, although they may still occur when looking through glass and other slightly reflective surfaces. When testing either of these distractions it may be best to not have these distractors occur as images on the screen the participant is looking at. This could cause a “don't think of a purple elephant effect” as the very existence of these obviously manufactured distractors on the screen would show deliberate intend to distract and so could hold special value to the participant.

If someone where intend on further investigating the decrease in amplitude when viewing the stimulus at an angle, then one way to approach this issue is by compensating for the angle. The experiment could use one stimulus set of normal faces shown at an angle, as was done in this study, and a second stimulus set which is also shown at an angle but which uses face images that compensate for being shown at an angle by having the far side be slightly larger than the near side. A larger amplitude in the second set could indicate that it is merely the distortion that causes a decrease in amplitude in the first set. It would be wise to test this within a larger study as there may not yet be enough evidential justification and therefore too high a chance of an insignificance to invest time and money in research that just uses those two conditions.

Finally when reproducing this experiment in whole or in part it may be worth it to add multiple degrees of angle and multiple steps of distance. If this has been done one could analyse if the effects are linear or quadratic. Knowing whether or not the effect diminishes over time and how rapidly, or if there's a consistent fall-off over time would prove very valuable in the case of amplitudinal decay. This is because if the amplitude of a scrambled face or neutral condition does not decay as rapidly, there may be a distance or an angle at which the face N170 and the non-face

N170 become indistinguishable from each other. This, in turn, would mean there is a limited range at which BCI using N170 could be used. When researching this it may be worth the extra time to check the effect of distance on peak timing. However, this is interesting mostly for the theoretical implications, as it may not impact BCI much even if it is possible to reproduce the result.

Implications

What was found in this study mostly serves as an inspiration for future experiments such as the ones described in the previous section. These experiments may be able to unearth underlying processes and so help add to what is known about the brain. However when seen on its own there are some practical implications to the findings done in this study. The first was that when using a BCI device that is placed within the ear, the N170 can be used in applications. The ideal application would be able to recognise an ERP in a single trail but this is not quite the case. However once this situation is reached the N170 can be used to detect that the user is looking at a face which the device could then scan and of which the Facebook profile linked to it could be opened. No doubt there are many people who do not fancy the idea of a device of the sort, but this is merely to show that this new knowledge can be used.

Furthermore it has become clear that distance and angle could potentially decrease the effectiveness of BCI devices as it was shown to reduce the amplitude of the N170 and so may also similarly impact other ERPs. To bring it back to the example application; knowing that distance affects the N170 means knowing this application won't work with faces that are more than a certain distance away. It further shows that the application may not be triggered when throwing a passing glance at someone who passes the user by due to the angle and so the privacy of people in the street may be protected by the limitation that the device will only work on people the user is talking to, or on people that are approaching the user.

Conclusion

Having this study as the basis; one could say that N170 experiments outside of the laboratory may be done using an ear-EEG device which uses the cheek as a reference, but that the position to the target should be taken into account as the N170 response will become less pronounced over larger distances and angles which could potentially create problems with distinguishing between the face evoked N170 and some neutral stimuli that also evoke an N170. These findings are in correspondence with the findings relating to the scalp-EEG. Furthermore there was a significant effect of distance on average peak timing, but the absolute value of this difference in means is so much smaller than the standard deviations that it is more interesting for its theoretical implications than its practical implications.

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