

Finding Evidence Accumulation in a Face Recognition Task

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Abstract

Theories of decision making propose that any single-stage decision can be represented as a process in which evidence is accumulated over time until it hits a decision threshold. The aim of this project was to develop memory and decision making tasks that were matched in perceptual stimuli and task difficulty such that we could test whether indeed the same or different neural mechanisms are involved in these two processes. We developed an experiment in which participants had to perform two tasks. The memory task was to remember two faces and judge whether a third face was the same; the perceptual task was to judge whether two tilted faces were the same. We showed that in both tasks, performance was around 80%. We also collected some preliminary EEG data.

1 Introduction

Previous studies have shown that making decisions is a process that is accomplished by accumulation of evidence (Ratcliff, 1978). Evidence is accumulated until a certain threshold has been crossed. However, this accumulation of evidence is a noisy process. In his paper, Ratcliff proposes a model for decision making: the drift diffusion model. The drift diffusion model is a way of explaining the speed-accuracy trade-off: the faster a decision is taken, the less likely it is to be accurate. When one takes a decision after careful consideration, the response is far more accurate. The drawback is that taking this carefully considered decision takes more time. The offered explanation for this phenomenon is accumulation until a certain threshold is breached. When this threshold is placed closer to the accumulation start, the accumulation process terminates sooner and speed is emphasized, whereas when the threshold is placed further away, accuracy is emphasized.

Recently, there has been a large body of research searching for neural correlates of these hypothesized ‘evidence accumulation’ processes (Shadlen & Newsome, 2001; Gold & Shadlen, 2007; Donner, Siegel, Fries, & Engel, 2009). In EEG, Van Vugt et al. found that 4-9 theta oscillations covaried with the dynamics of evidence accumulation predicted by the drift diffusion model (M. K. Van Vugt, Simen, Nystrom, Holmes, & Cohen, submitted). The task they used to detect these oscillations was a standard perceptual decision making task that made use of moving dots (Britten, Shadlen, Newsome, & Movshon, 1993). These dots were moving in a fixed direction. Participants had to decide whether

the dot was moving left or right. The dot was sometimes moving randomly, instead of in a fixed (left or right) direction.

Van Vugt et al.'s research has shown that the evidence accumulation process correlates in oscillatory power with the 4-9 theta band (M. K. Van Vugt, Simen, Nystrom, Holmes, & Cohen, 2011). Van Vugt et al. did this by repeating the moving dots experiment, while collecting EEG data, and then using a model-based EEG analysis to extract patterns of EEG data that followed the dynamics predicted by the drift diffusion model.

The evidence accumulation process has not only been observed in EEG. In MEG-studies concerning perceptual decisions, researchers found motor response-selective MEG activity in the 64-100 Hertz gamma and 12-36 Hertz beta ranges that predicted the subjects choice before they explicitly 'manually' replied (Donner et al., 2009). This activity was gradually building up, supporting the theories on evidence accumulation (Donner et al., 2009). The MEG activity in these ranges indicated a gradually building certainty about the right answer of the perceptual decision task, a task in which participants had to respond whether they saw or missed the target in a presented image.

Correlates of an evidence accumulation process have also been seen in fMRI-studies; by studying the sensory discriminatory ability, researchers found that sensory discriminatory tasks show a form of evidence accumulation (Heekeren, Marrett, & Ungerleider, 2008). These tasks consisted of two visual, auditory and somatosensorial components, each consisting of answers that were either 'yes' or 'no'. This fMRI-study found neural correlates that were consistent with the drift diffusion model in a tactile decision experiment.

Originally, the drift diffusion model was described as a model for recognition memory (Ratcliff, 1978). However, the recent neuroscience research (M. K. Van Vugt et al., 2011) has focused on perceptual decision making. In this paper, we develop a pilot to examine whether similar neural correlates can be found for recognition memory decisions as for perceptual decisions. In order to keep the tasks as similar as possible, the tasks have to be matched in stimulus content, difficulty and accuracy. These aspects are analyzed for similarity and we collect some preliminary EEG data to check whether the EEG-setup is suitable.

Both the perceptual decision task and the memory task involve judgments about face stimuli. These face stimuli come from a well-defined perceptual space (Banz & Vetter, 2003), such that the effect of stimulus similarity on the decision making processes can also be studied. The perceptual decision task consists of two faces, of which the participant has to say whether they are the same face. The memory task is a bit more complex. First, two faces are shown. After showing these two faces, a third face is shown. The participant must decide whether this face is equal to one of the other two faces shown previously. These trials are essentially 'yes'/'no' questions. To extract patterns of neural data consistent with evidence accumulation, we make regressors that reflect evidence accumulation dynamics to pull out EEG data that correlates with the evidence accumulation.

In order to find the evidence accumulation, we use the same technical setup as Van Vugt et al. in their EEG research (M. K. Van Vugt et al., 2011). The EEG described in

this paper is only a small part of the big picture: we plot an ERP of the C_z electrode as a basic test for checking whether the set-up is suitable in terms of the proposed EEG-analysis. We also plot a target-lure ERP to support the claim that the presented stimuli are similar.

2 Materials and Methods

2.1 The Face Space

As has previously been discussed, the memory and perceptual tasks make use of carefully parametrized stimuli from a particular face space. (M. Van Vugt, Sekuler, Wilson, & Kahana, in press) details the importance of this approach. Our experiment makes use of faces generated according to the face space as described by Blanz and Vetter (Blanz & Vetter, 2003). This space is defined by the automatic generation of faces in layers of standard deviations. These standard deviations are calculated according to a database of faces (Blanz & Vetter, 2003).

Our experiment uses faces varying with a distance of three different standard deviations for three different facial properties. These three facial properties are represented by three directions: the principal components of a front view of a face, the principal components of a side view of a face and the principal components of a profile view of a face (Blanz & Vetter, 2003). These three properties are each averaged and have their own set of standard deviations ($-\sigma$, 0 and $+\sigma$). This brings the total amount of faces used in a task to 27.

In the analysis of our pilot, a presented face is stored as the set of three properties it differs in. A face with $-a\sigma$ in the front view of the face, $+a\sigma$ in the side view of the face and 0σ in the profile view of the face, is as such equal to the vector $[-a, +a, 0]$. The pilot we have developed makes use of two different values for a : 2 and 3. Example faces could as such be $[3, 3, 0]$ (Fig. 1) or $[0, -2, 2]$.



Figure 1: The face represented as vector $[3, 3, 0]$

2.2 The Task

The task consists of twelve different blocks, each four minutes long. These twelve blocks are divided in four parts, each three blocks in length. In these parts, the first two blocks are perception tasks and the third block is a memory task. The faces used in these two tasks are drawn from the earlier described face space. Both tasks consist of distinguishing the faces: different faces are to be answered with ‘no’ and similar faces are to be answered with ‘yes’. If the participant thinks the faces are different, they press the z-button; if the participant thinks the faces are the same, they press the m-button.

Participants are rewarded based on the amount of correctly answered trials, not based on accuracy. Each correct answer yields two euro cents, so to maximize earnings, a participant wants to do as many trials as possible. Deciding too quickly leads to many errors, so the participant has to find the optimal speed-accuracy trade-off (SAT). Previous studies have shown that participants are well able to optimize this SAT (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006).

Before each experiment, we randomize the order of the blocks that participants are offered. This is done to prevent artefacts that result from any coincidental effects with a certain order of the faces. Each block is separated with an explanation of the perceptual/memory task that the participant has to perform in which participants can rest for as long as they want. Between each trial, there is an approximately two seconds long delay before the next trial starts.

2.2.1 The Perceptual Task

The perception task consists of two tilted faces (Fig. 2) that have to be compared by the participant. One of these faces is tilted to the right and one of these faces is tilted to the left. The algorithm that presents the faces, presents them with a 50% chance of being similar or different. As such, if the participant were to respond randomly, one would expect a 50% correctness rate independent of the participant always replying ‘yes’ or always replying ‘no’. The two faces distinction task allows us search for neural correlates of evidence accumulation in perceptual decisions.



Figure 2: An example of the perception task

The perceptual task makes use of the two standard deviations setting. This implies that faces can differ from 0 to 12 standard deviations, the most extreme difference being a face defined as $[-2, -2, -2]$ versus a face defined as $[2, 2, 2]$.

2.2.2 The Memory Task

The memory task consists of two parts: first, two faces are shown (Fig. 3), after which a third face is shown. The participant has to recall whether any of these two faces matches the third face. The first two faces are, in a specific trial, never the same face. The third face has a 50% chance of differing from the two initial faces. The participant can answer as soon as the third face is shown.

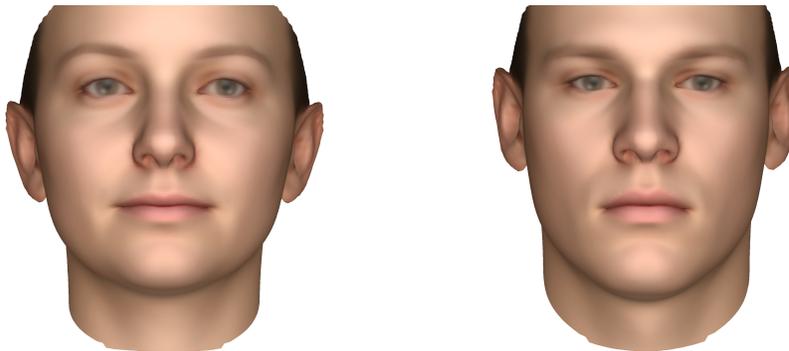


Figure 3: An example of the memory task stimuli

Faces in the memory task stimuli are made with the three standard deviations setting and can differ up to eighteen standard deviations, but as they are never the same, they differ at least three standard deviations. As a result, the least similar faces are $[-3, -3, -3]$ versus $[3, 3, 3]$.

2.2.3 The General Setup

The pilot that is discussed is the final version of the pilot. We have tested a previous version in which the memory task had a standard deviation setting that was similar to the setting in the perceptual task (2σ), but this resulted in an accuracy that is too low. Low accuracy is unwanted for two particular reasons: the accuracy needs to be high enough to rule out any random guessing chances, and the memory accuracy should match the perceptual accuracy as much as possible to keep the diffusion processes as similar as possible.

The analysis consists of 20 participants (8 female). Their ages range from 18 to 36 years old. All of the participants are right-handed. Of these 20 participants, 14 did an EEG session. 3 of the participants performed more than one session, but no participant has done EEG twice.

Participants are instructed beforehand, but can also read the instructions between the blocks. Participants were specifically instructed to find a balance between quick and accurate answers to maximize their earnings. The instructions before the experiment were

given in the native language of the participant. The instructions between the blocks were given in Dutch. As only 2 of the 20 participants were not native Dutch speakers and they received an explanation beforehand (they mentioned that they fully understood the task), this should have no significant effects.

2.3 Comparing the two tasks

The main attributes that we measure during the experiment are the accuracy, the reaction times for each trial and which faces are presented in each trial. This comparison between the faces is so that we can study the effects of the presented faces on the performance of the participant. This is further discussed in the ‘The Similarity Space’ section.

In order to achieve the main goal, namely a memory and a perceptual task that only differ in the remembrance aspect, we compare the measured attributes and draw a conclusion. If the measured attributes fit to our expectations in terms of accuracy, reaction times and similarity (as described later in this section), then we can say that the pilot is reliable enough to use for testing the final hypothesis that memory tasks show similar evidence accumulation processes as perceptual tasks.

Each memory trial can be either a target or a lure trial. A target trial is one in which the participant should answer ‘yes’; a lure trial is a trial in which the participant should answer ‘no’. Each perception trial can either be a match or a non-match. Match trials should be responded to with ‘yes’, while non-match trials should be responded to with ‘no’.

For the accuracy, we aim for scores around 80% (as such, we expect our pilot participants to score around 80%). This is to exclude any effects due to randomness, which equal 50% due to the answers being either ‘yes’ or ‘no’. The accuracy of 80% also rules out ceiling effects that could arise. Ceiling effects would still prevent us from carefully comparing the data, as the perceptual and memory conditions could be completely different, but both easy enough to lead to ceiling effects. We expect the perception and memory task show no significant differences in accuracy. We also study the learning curves, to see whether performance improves/declines during the task.

The reaction time for each trial is measured to give a general impression of the distribution of the reaction times. We consider standard decision making tasks, so we expect normally distributed data with a skew to the right.

2.4 The EEG Setup

The EEG-setup that we use is similar to the Van Vugt setup (M. K. Van Vugt et al., 2011) that is described as useful for decision making processes by Kononowicz and Van Rijn (Kononowicz & Rijn, 2011). We recorded electrical brain activity from 30 scalp locations: FP1, FP2, AFz, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, O2, FC1, FCz, FC2, FC5, FC6, CP5, CP1, CPz, CP2 and C6. We measured the vertical and horizontal EOG activity and both mastoids with reference electrodes. The impedances of both the reference electrodes and the EEG cap were kept below $15k\omega$ (10 caps and reference electrodes of participants were kept below $10k\omega$).

We also perform some exploratory ERP analyses. The first ERP is an analysis of memory and perception potentials, whereas the second ERP is an analysis of lure- and target effects (Jacobs, Hwang, Curran, & Kahana, 2006). Both of these analyses are performed to strengthen our claim that the memory and perceptual tasks are similar in stimulus content. Our pilot study has focused on the C_z -region. We apply a filter for the 48-52 Hz region, to reduce line noise.

2.5 The Similarity Space

The original drift diffusion model (Ratcliff, 1978) consisted of four different conditions. Each condition was a state of coherence between target trials and lure trials with one stimulus and one probe. The first condition was a high coherence target trial condition: the high coherence resulted in a quick response. A similar result was found in the low coherence lure trial condition: the stimulus and probe were different to such an extent that the response was quick. The two moderately coherent conditions had longer response times: it was harder to take a decision.

In order to calculate the difference between the faces, we use the euclidean distance to measure face space distances (Kahana & Sekuler, 2002). Each of these euclidean distances represents a different coherence level, so in order to reliably study the evidence accumulation processes in the pilot, we need to find whether the similarity of the faces has effects that concur with our expectations. We expect three different similarity effects. The first is the similarity between the stimuli in the memory tasks. The second way the similarity between the two presented faces in the perception task. The third is a comparison between the two stimuli and the probe in the memory task.

For checking whether the similarity of the faces acts according to our expectations, we plot the probability that the participant answers ‘yes’ (the probability that the participant thinks this is a target trial) versus the euclidean distances the generated faces yield.

The interstimulus similarity in the memory and perception conditions are calculated using the same formula (eq. 1), the only difference between memory and perception being that memory adheres to 3 standard deviations, whereas perception adheres to 2. Values for this equation could (in the case of a memory trial), for example, be vectors $v1 = [3, 3, 0]$ and $v2 = [-3, 0, -3]$. This value is defined as the interstimulus similarity distance that has a certain probability of the participant answering ‘yes’.

$$d(p, q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + (p_3 - q_3)^2} \quad (1)$$

Calculating the euclidean distance of stimulus similarity (p = face vector 1, q = face vector 2)

Euclidean distances for the stimulus-probe similarity are calculated by adding the euclidean distance between the first face and the probe and the second face and the probe. For example, the stimuli $[p_1, p_2, p_3]$ and $[q_1, q_2, q_3]$, combined with the probe $[r_1, r_2, r_3]$, would yield the euclidean distance represented in equation 2.

$$d(p, q, r) = \sqrt{(p_1 - r_1)^2 + (p_2 - r_2)^2 + (p_3 - r_3)^2} + \sqrt{(q_1 - r_1)^2 + (q_2 - r_2)^2 + (q_3 - r_3)^2} \quad (2)$$

Calculating the summed euclidean distance of stimulus-probe similarity (p = stimulus face vector 1, q = stimulus face vector 2, r = probe face vector)

3 Results

3.1 Accuracy and Reaction Times

The plot for the task accuracies shows the average accuracy of the 20 participants in the memory and perceptual tasks (Fig. 4). The accuracy for the memory task is around 75%, whereas the accuracy for the perception task is slightly below 80%. This is not the 80% we had hoped for, but it is a satisfactory result nevertheless: we are far from both the 100% accuracy of ceiling effects ($t_{mem}(19) < 0.001, s.$; $t_{perc}(19) < 0.001, s.$) and the 50% accuracy of random guessing ($t_{mem}(19) < 0.001, s.$; $t_{perc}(19) < 0.001, s.$). The error bars overlap, so the accuracy of the tasks are approximately the same. The difference between the tasks is significant ($t(19) < 0.01, s.$), however, so the task performance is significantly different.

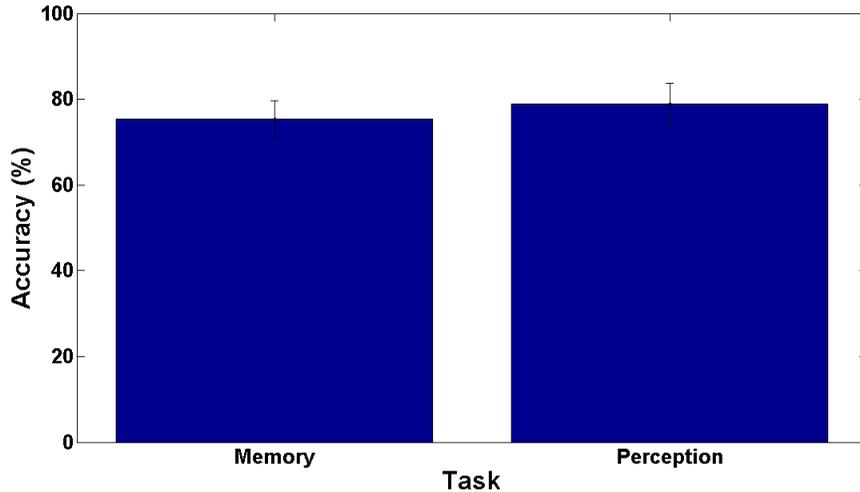


Figure 4: The average accuracies for the tasks

The reaction times for memory are normally distributed with a skew to the right (Fig. 5, left). Another thing we can see from the reaction times is that the average task performance is fairly similar between participants. The reaction times for perception are also normally distributed with a skew to the right (Fig. 5, right), with one exception, a participant that had non-normally distributed reaction times up to 7 seconds. Analysis has deemed the reaction times of this participant a definite outlier. As such, the reaction

times of both memory and perception show a normal distribution with a skew to the right: they are evenly matched.

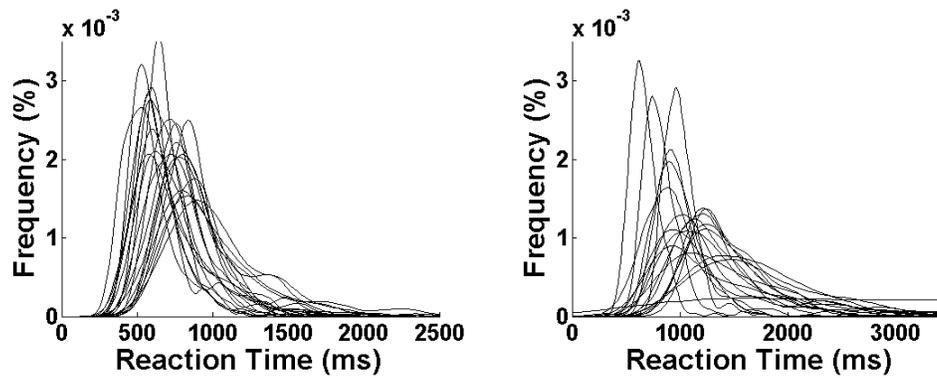


Figure 5: The memory (left) and perception (right) task reaction times curve for each participant

3.2 Learning Effects

3.2.1 Interblock Learning Effects

Analysis of the interblock learning curves has shown no significant results ($t_{mem}(7) = 0.77$, n.s.; $t_{perc}(3) = 0.75$, n.s.). The interblock learning curve for the memory task (Fig. 6) shows a fairly straight regression line. The interblock learning curve for the perception task shows us a regression line detailing a consistent performance around 80% (Fig. 7).

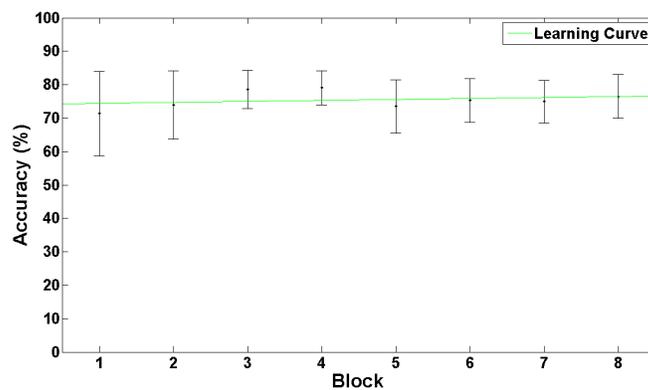


Figure 6: The learning curve for the memory task

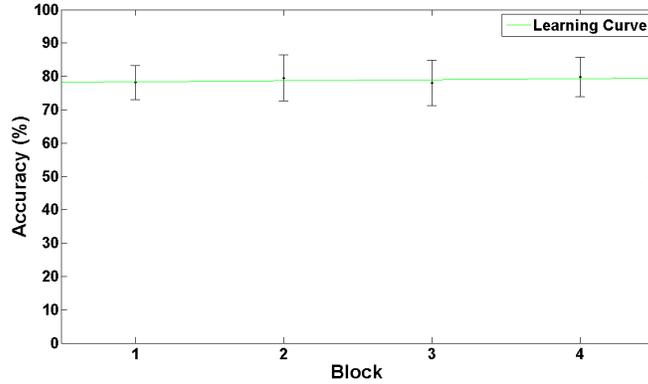


Figure 7: The learning curve for the perception task

3.2.2 Interexperiment Learning Effects

Analysis of the three repeat participants has shown that there is no significant difference in their performance between the two experiments ($t_{mem}(2) = 0.67$, n.s.; $t_{perc}(2) = 0.23$, n.s.). All three participants have shown to perform fairly consistent in the memory task (Fig. 8), with the error bars showing no signs of interexperiment significance. The performance for the perception task shown some difference, with improvements for each participant (Fig. 9). However, both the error bars and the $t_{perc}(2)$ of 0.23 show that this improvement is not significant. If we were to use repeat participants to improve the performance (that we have already concluded to be satisfactory), their improvement would not be significant enough to be worth the effort.

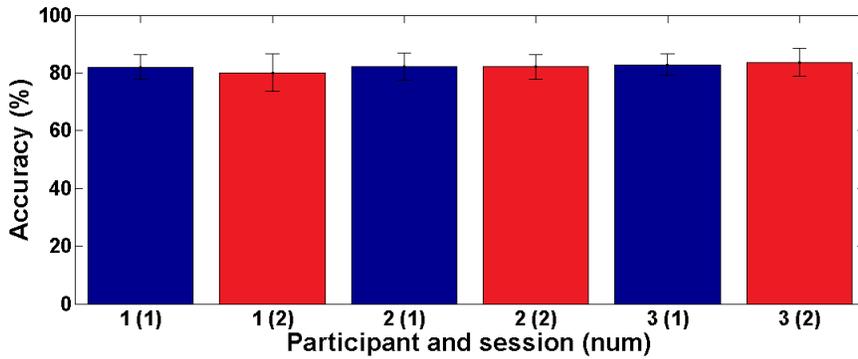


Figure 8: The accuracies for the memory task by repeat participants

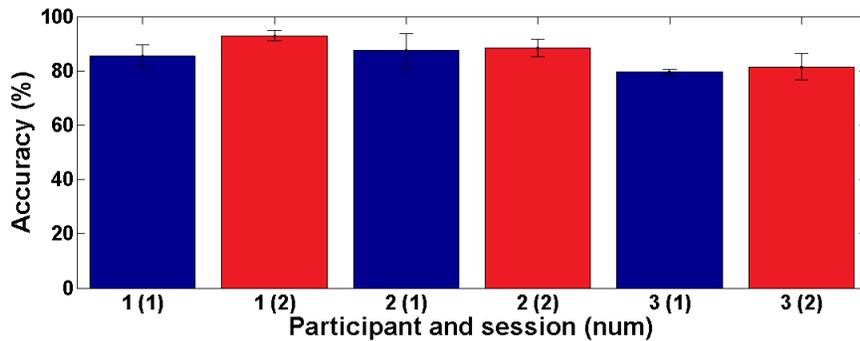


Figure 9: The accuracies for the perception task by repeat participants

3.3 Similarity Effects

3.3.1 Stimulus-Probe (Memory)

For the target trials, the probability of ‘yes’ decreases as the euclidean distance grows (Fig. 10). This is according to expectations, because a smaller difference greatly improves the probability of the probe matching one of the stimuli, as there are only three properties with just three standard deviation settings. If two of these stimuli faces, such as $[3, 3, 0]$ and $[3, 3, 3]$, are similar, the probability of a probe face with value $[3, 3, x]$ having either $x = 0$ or $x = 3$ is greater than when the stimuli faces were completely different.

For the lure trials, the probability of ‘yes’ also decreases as the euclidean distance grows (Fig. 10). This is because a greater dissimilarity makes it easier for the participants to recognize the fact they are dealing with a lure trial, prompting them to answer ‘no’ more often.

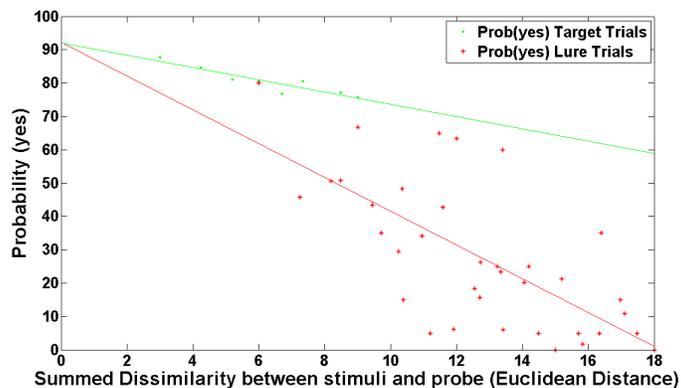


Figure 10: The probability of ‘yes’ for summed dissimilarity. Each dot represents a certain euclidean distance between faces.

3.3.2 Interstimulus (Memory)

For target trials, the probability of ‘yes’ decreases as the euclidean distance grows (Fig. 11). This is according to expectations: after all, a growing euclidean distance suggests a greater difference in the presented faces. This makes it harder for the participant to remember the presented faces. This inter-item similarity factor has also been discussed by Kahana and Sekuler (Kahana & Sekuler, 2002). As the difference in these faces grows, the participant is more likely to make an error. As such, with a greater dissimilarity, the participant answers ‘no’ more often.

For lure trials, the probability of ‘yes’ increases as the euclidean distance grows (Fig. 11). This, too, is according to expectations: if the presented stimuli are similar, the probability of the participant thinking the probe face is similar to the stimuli, is greater. This makes the participant more inclined to answer ‘yes’, while there is in fact a lure trial.

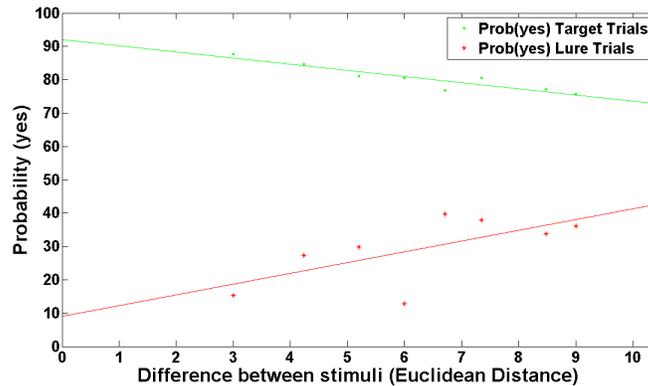


Figure 11: The probability of ‘yes’ for memory stimulus similarity. Each dot represents a certain euclidean distance between faces.

3.3.3 Interstimulus (Perception)

For match trials, there is a straight line around 80% (Fig. 12). This is what we expected: a single point with a fairly high probability of answering ‘yes’ (a successful pilot would give the aforementioned 80%). This is because there is only one euclidean distance associated with the target trials: 0. A trial in the perceptual condition is only a target trial when the faces are identical.

For non-match trials, the probability of ‘yes’ decreases as the euclidean distance grows (Fig. 12). This is what we expected: as the faces grow more different, a participant realizes that they are different more often. As such, they respond ‘no’ more often, decreasing the probability of them answering ‘yes’.

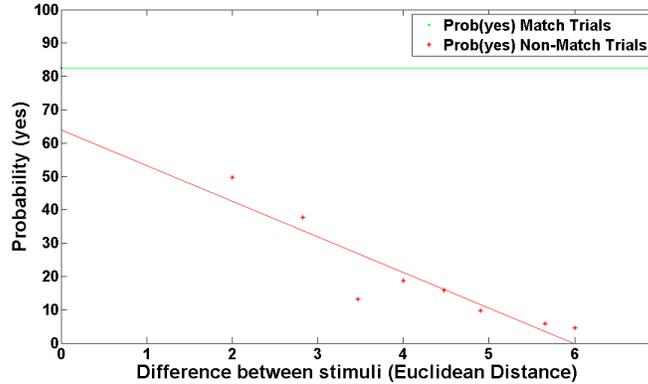


Figure 12: The probability of ‘yes’ for perceptual similarity. Each dot represents a certain euclidean between faces.

3.4 Preliminary EEG Results

3.4.1 ERP of the C_z region

In order to see whether the perception and memory tasks are at a similar level, the ERP of the memory and the perception task should not be too different. We observed increased activity in the memory and perception trials around 50 ms and 150 ms (indicated by the potential in Fig. 13). The biggest difference between the memory and perception trials is the height of the potential after 150 ms: for memory, this potential remains positive, whereas for perception, this potential remains negative for a while, taking a longer time to become positive again. They show a similar trend, but the perceptual potential is $1\mu v$ lower than the memory potential after 150 ms.

A higher memory potential is not a strange fact: after the stimuli have been presented, a participant is primed to respond. For the perception trials, this is never the case: a participant has full control of when he ‘makes’ the decision, without the priming effects. As such, the difference between the memory and perception tasks is because of priming. The rest of the ERP pattern is similar: the ERPs are alike enough to support the hypothesis that the pilot is sufficient to test for similar neural correlates in the perceptual and memory decision making.

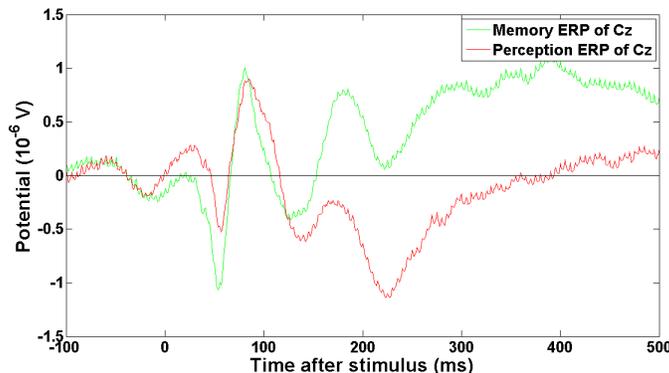


Figure 13: The ERPs of the C_z -region for the memory and perception task

3.4.2 Target versus lure ERP of the C_z region

We studied the target versus lure ERP in order to study the target-lure confidence (Jacobs et al., 2006), as the target-lure confidence follows the same drift diffusion model as the evidence accumulation processes. We observed increased activity in the target and lure trials around 50 ms and 150 ms (indicated by the positive potential in Fig. 14). The trial and lure potential hardly differ until 300 ms. After this, the lure potential is slightly larger than the target potential. This is opposite of what Jacobs et al. have found (Jacobs et al., 2006): lure trials are not primed and should as such have less potential than target trials.

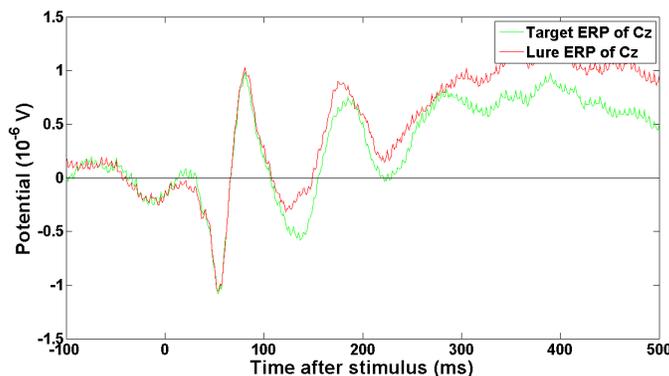


Figure 14: The ERPs of the C_z -region for the target and lure trials

4 Discussion

4.1 Conclusion

The results section has shown us that the pilot participants can perform both memory and perception tasks with about 75-80% accuracy, similar performance on the perception

and memory tasks, a normal distribution in the reaction times with a skew to the right and expected similarity effects. As the memory and perception tasks are equal in stimulus content and difficulty, we can accept the hypothesis that the pilot is suitable for testing the final hypothesis.

4.2 The final hypothesis

Most of our research has focused on the pilot, but as has been previously mentioned, the project is ultimately meant to find the neural correlates of evidence accumulation in perceptual and memory tasks and seeks to compare these neural correlates, with the expectation that the oscillations in the 4-9 hertz theta band prove to be the most successful candidate. Half of the participants (about 17) for this future research have already performed the tasks while their EEG was measured. As such, when the pilot refers to 14 EEG participants, these participants have in fact been doing the task that seeks to confirm the final hypothesis that perception and memory tasks show the same oscillations in the 4-9 hertz theta band. Thus, these participants are also used for the experiment we initially sought to perform: in order to find the answer to our final hypothesis, all that remains is some data collection and a final analysis of their EEG data.

4.3 Targets versus Lures ERP

Our EEG analysis for the targets and lures has shown that the ERP for lure trials after 300 ms is higher than the ERP for target trials after 300 ms. This is somewhat remarkable: one would expect that the potential for lure trials would be lower, as target trials are primed. There may be factors such as task difficulty (perhaps the target trials are inherently more difficult, since there are very few ‘sufficiently’ similar faces in a face space of 27 faces making it hard to identify some of the targets as target trials, whereas it is easy to find lures that are easy to identify as lure trials).

4.4 Future Research

As the targets versus lures ERP and the significant difference between the memory and perceptual accuracies have shown, the pilot is not perfect. While we have concluded that the pilot is satisfactory (because the other factors that we have discussed make up for these discrepancies), this opens up possibilities for future improvement. Future research could focus on making the memory and perceptual task even more similar. By experimenting with the standard deviations setting (the current is 2σ for the perceptual tasks and 3σ for the memory tasks), participant task performance can be tweaked. This would account for more statistical validity for the final hypothesis if it is confirmed.

If the final hypothesis indeed turns out to be correct, it would show that similar neural correlates of evidence accumulation can be shown in both perception and memory tasks. This result can be used to prove that evidence accumulation indeed occurs in memory tasks. Future research can use this notion to expand the knowledge of the memory acquisition processes and decision making as a whole. By knowing that evidence accumulation occurs in memory tasks, one could use these accumulation processes as a basis for a formal model of memory-based decision making. This model would bring us one step closer to fully understanding the processes in the human brain.

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