COMENIUS UNIVERSITY IN BRATISLAVA

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

INFLUENCE OF RESPONSE TYPE ON P300 ELICITED IN ODDBALL TASK

Diploma Thesis

Bratislava 2017 **Bc. Peter Buzáš**

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Study programme: Cognitive Science

Field of Study: Cognitive Science

Department: Department of Applied Informatics

Supervisor: RNDr. Barbora Cimrová, PhD.

Bratislava 2017 **Bc. Peter Buzáš**

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Univerzita Komenského v Bratislave
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ZADANIE ZÁVEREČNEJ PRÁCE

Meno a priezvisko študenta:	Bc. Peter Buzáš
Študijný program:	kognitívna veda (Jednoodborové štúdium, magisterský II. st., denná forma)
Študijný odbor:	kognitívna veda
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Názov: Influence of response type on P300 elicited in oddball task
Vplyv typu odpovede na kognitívny evokovaný potenciál P300 vyvolaný úlohou oddball

Cieľ: Vypracujte literárny prehľad o kognitívnom evokovanom potenciáli P300 vyvolanom pomocou paradigmy oddball. Urobte experimentálny dizajn zahŕňajúci nový typ odpovedania pri tejto úlohe. Vyhodnoťte dáta a overte, či a akým spôsobom sú výsledky ovplyvnené typom odpovede.

Literatúra: Huettel S.A., McCarthy G. (2004). What is odd in the oddball task?: Prefrontal cortex is activated by dynamic changes in response strategy. Neuropsychologia, 42(3), 379-386.
Polich J. (2007). Updating P300: an integrative theory of P3a and P3b. Clinical Neurophysiology, 118(10), 2128-2148.
Squires N.K., Squires K.C., Hillard S.A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 38(4), 387-401.

Anotácia: Oddball paradigma je založená na prezentácii cieľového nefrekventovaného podnetu v sekvencii štandardných frekventovaných podnetov. Participant je inštruovaný mentálne alebo motoricky reagovať na cieľové podnety a ignorovať ostatné podnety. Prezentácia cieľového podnetu vyvolá pozitívny kognitívny evokovaný mozgový potenciál s latenciou približne 300ms (P300). K rozšíreniu poznatkov (kontextuálny, emočný oddball) by mohli dopomôcť drobné zmeny v dizajne tejto paradigmy. Nato je však nutné zodpovedať ďalšie otázky, napríklad, aký je vplyv spôsobu odpovede na vyvolanú mozgovú aktivitu.

Vedúci:	RNDr. Barbora Cimrová, PhD.
Katedra:	FMFI.KAI - Katedra aplikovanej informatiky
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THESIS ASSIGNMENT

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Field of Study:	Cognitive Science
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Language of Thesis:	English
Secondary language:	Slovak

Title: Influence of response type on P300 elicited in oddball task

Aim: Review the existing literature on the P300 event-related potential elicited in the oddball paradigm. Carry out the experimental design including a new type of responding in the oddball paradigm. After the experiment, process and analyze the obtained data and find out if and how the results were influenced by the new response type.

Literature: Huettel S.A., McCarthy G. (2004). What is odd in the oddball task?: Prefrontal cortex is activated by dynamic changes in response strategy. Neuropsychologia, 42(3), 379-386.
Polich J. (2007). Updating P300: an integrative theory of P3a and P3b. Clinical Neurophysiology, 118(10), 2128-2148.
Squires N.K., Squires K.C., Hillard S.A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 38(4), 387-401.

Annotation: Oddball paradigm is based on the presentation of infrequent target stimuli in the sequence of frequent standard stimuli. Participant is instructed to respond mentally or physically to target stimuli and to ignore other stimuli. Presentation of a target stimulus elicits a positive event-related potential with latency 300ms (called P300). To enrich the current knowledge about the topic (e.g. with emotional or contextual oddball), it might be helpful to slightly modify the classical design. But first we would need to answer some additional underlying questions, e.g., what is the influence of response type on the elicitation of P300.

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At this point I would thank all the people that in one or another way helped me with my thesis. First of all I would like to thank my supervisor Barbora Cimrová for her enthusiasm, dedication and hard work on my behalf and all of her advice and knowledge she hopefully passed down on me. My other big thank you goes to Grega Repovš who gave me the opportunity to work with him and the team in the Mind and Brain laboratory of the Department of Psychology of University of Ljubljana and who had the patience for my questions. I would also like to thank Anka Slana who helped me find my way around the lab and was always willing to explain. I would also like to thank everyone from our research team as we were working together in the lab, namely Andraž Matkovič, Sanja Roškar, Neža Vehar, Nastja Tomat and Maroš Rovný. We spent a lot of time together trying to figure it all out and I will always remember you fondly. And last but not least I would love to thank my family and loved ones, to put up with me and to provide me with suitable conditions so I could write. Thank you all.

Abstrakt

BUZÁŠ, Peter. *Vplyv typu odpovede na kognitívny evokovaný potenciál P300 vyvolaný úlohou oddball* [diplomová práca]. Univerzita Komenského v Bratislave. Fakulta matematiky, fyziky a informatiky; Katedra aplikovanej informatiky. Školiteľ: RNDr. Barbora Cimrová, PhD. Bratislava : FMFI UK, 2017. 41 s.

Cieľom tejto štúdie bolo zistiť ako vplýva typ odpovedania na evokovaný potenciál P300 v úlohe oddball. Za týmto účelom sme porovnali tri spôsoby odpovede. Dva tradične používané – stláčanie tlačidla pri cieľovom podnete a mentálne počítanie cieľových podnetov a jeden nový – stláčanie tlačidla pri každom podnete, jedno pri cieľových podnetoch a jedno pri štandardných a rušivých podnetoch. Tieto tri spôsoby odpovede sme porovnali zvlášť pre sluchové a pre vizuálne podnety. Našli sme štatisticky vysoko významný efekt typu odpovedania na evokované potenciály P300. Na základe našich výsledkov však prichádzame k záveru, že napriek drobným rozdielom vo výsledkoch bude možné tento nový spôsob odpovede používať, ak mu bude ešte venovaná dostatočná výskumná pozornosť.

Kľúčové slová: evokované potenciály, P300, oddball paradigma, typ odpovede.

Abstract

BUZÁŠ, Peter. *Influence of response type on P300 elicited in oddball task* [Diploma thesis]. Comenius University in Bratislava. Faculty of Mathematic, Physics and Informatics; Department of Applied Informatics. Supervisor: RNDr. Barbora Cimrová, PhD. Bratislava: Faculty of Mathematics, Physics and Informatics UK, 2017. 41 p.

The aim of this study was to find out how does the response type influence the P300 evoked potential in the oddball task. For this purpose we compared three ways of responding. Two traditionally used – pressing a button to target stimuli and mental counting of stimuli and one new way – pressing a button to every stimulus, one to target stimuli and one to standard and distractor stimuli. We compared these three methods of responding with auditory and visual stimuli. We found statistically highly significant effect of response type on P300 evoked potentials. Based on our results we conclude that this new type of responding may be used in the future if enough research attention is given to it.

Key words: Event related potentials, P300, oddball paradigm, response type.

Foreword

Ever since the discovery of P300 component of the event-related potentials 50 years ago it has been an inspiration for many studies and research designs regarding cognition and decision making. One of the best and most commonly used ways to elicit P300 evoked potentials is the response oddball that has been around for about 40 years now and it has proven to be very effective in this task. There have been some efforts to include emotions in the oddball task, however a task where the stimuli used would be all emotionally charged has not yet been done. To see how would the emotional component influence the results we would have to get behavioural data for every kind of stimulus used in the oddball paradigm – the frequent non-target (standard), the infrequent target and the infrequent non-target (distractor) - in our case by pressing the corresponding button to indicate whether it was the target stimulus or a different one. But as this was never done before we had to make sure responding to all stimuli would not change the fundamental way the oddball paradigm works and performs. To do this we decided to compare the two standard ways of responding to oddball task which are responding to target stimulus and counting – keeping track of target stimuli in one's mind and adding the number of their occurrences mentally and our new method of responding by one button to the target stimuli and by another button to all the other stimuli (standards and distractors). To be thorough enough we also decided to test this using stimuli of both auditory and visual modalities.

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Introduction

The link between cognition and emotion is well-known in the scientific community, but how they interact exactly is not yet adequately explored. One of the great phenomena used to study cognition is the P300 component of event-related potentials was first reported a half-century ago, but remains a prominent facilitator of research of cognition. There are still many questions to be answered about its nature, neural correlates or underlying mechanisms, but it still provides us with new research possibilities and new data. Probably the most widely known and used way to elicit these potentials is the oddball paradigm. It was first used more than 40 years ago and has seen many variations and has been used for a lot of different purposes. The version of the oddball task usually referred to as the 3-stimulus oddball which is the one we used in our present study is responding to infrequent target stimuli occurring among frequent standard stimuli and infrequent non-target stimuli that are not to be responded to. Although there have been studies linking P300 with emotion as well as some efforts to introduce emotionally charged stimuli into oddball paradigm an experimental design using a 3-stimulus oddball solely with emotional stimuli has not yet been conducted. These facts led to an idea to create such a design on which perhaps some new findings about the relation between emotion and cognition could be made. However in order to be able to do such experiment we would need behavioural markers (e.g. reactions by pressing buttons) for every type of the three kinds of stimuli in the response oddball and not only for target stimuli as it is common. This would be needed because the emotional valence of the stimulus might change how the stimuli are processed and having these markers would allow us detect and analyse such occurrences. Hence we came up with a design to test our research question: What is the influence of responding to every stimulus in the oddball task across two modalities (auditory and visual) compared with the results with two commonly used types of responding (responding to only target stimuli and mental counting of targets)? These series of experiments and the analysis and discussion of the results will be our main research priorities. Other than that in our thesis we will provide the reader with a review of relevant literature on this topic. We will define the phenomena we are dealing with and explain basic mechanism known about their nature. We covered findings by previous studies so that we would have a mean to compare our data to see if the design was valid and we prepared an overview of methods used to localize peak amplitudes in EEG data used in evoked potential research. Based on the data from previous experiments we hypothesized what the results of the experiment will be. Our null hypothesis states therefore that the new way of responding to oddball task, will not influence standard results. In the methods section we go through the breakdown of our methods and explain statistics we used to analyse the data. We report our results that have provided some significant effects and interactions that are consistent with previous works using the oddball task as well as bringing new light to our research question.

1 P300

The P300 is a cognitive component of the event related potentials that is usually, as the name suggest, elicited approximately 300 ms after the presentation of the stimulus. However it is not linked to any physical attributes a stimulus has, but rather to how the stimulus is evaluated by the subject. The P300 evoked potential wave was first reported by Sutton et al. in 1965 a bit over 50 years ago and it facilitated the search for cognitive explanations of its origin. Sutton and colleagues have discovered about five components in their experiments but they have focused on only two of those: a negative response with an average latency of about 100 ms and a positive component occurring with an average latency of about 300 ms. (Sutton et al., 1965). This component was later named P300.

At this point, we have used several ways to describe or refer to the P300 evoked potential and therefore we would like to set some terminology for the sake of consistency. To refer to this ERP component the term “P300” or “P3” is commonly used. Earlier papers and studies including the one of Sutton and his colleagues sometimes also use the term “late positive component”. And then for the subcomponents of P300 the terms “P3a” and “P3b” are used respectively as we will address these later. (Polich, 2007)

One of the most common and widely used ways to elicit a P300 potential is by utilizing the *oddball paradigm.*

1.1 Oddball paradigm

The oddball paradigm is a type of behavioural task in which subject is presented by a frequently occurring non-target stimuli and an infrequent target stimuli that occur on their background. The participant is tasked with responding to these target stimuli. This is the standard design of the oddball task very similar to the original task used by Squires and colleagues in 1975 which we will cover later, however there are two other widely used variants of the oddball design one of which is the one we used in our experimental setting. These are the *single-stimulus* and *three-stimulus* oddball. (Pollich, Criado; 2006)

The single stimulus oddball the subject is presented only with the infrequent target stimuli. In this variant the role of frequent standard stimuli are substituted by absence of stimuli of random durations. (Katayama, Polich; 1999)

The three stimulus is another variant of oddball paradigm that is being used more widely in the recent time. In this variant there is a new stimulus added. It is an infrequent non-target stimulus that participants are not supposed to respond to. It is usually called ‘distracter‘.(Katayama, Polich; 1999) We however prefer the term distractor which we will be using hence in this thesis. This is also the variant we also employed in our research design and so we refer to it as oddball without specifying it being a variant.

1.2 Origin of Oddball paradigm

The original study using what became later known as the oddball task was written by Squires and colleagues and published in 1975. Following the findings of Sutton and his collaborators about the P300 evoked potential and the work of other authors, Squires and team decided to try to resolve some of the questions that arose from discrepancies in the reported data. Most authors stated the latencies of P300 in the interval between 300-450 ms but there had been reports ranging from 210-220 ms to 450-550 ms. Other differences in latencies were found in P300 evoked by shifts in tone bursts and those evoked by the changes in stimuli probability. To find answers to these questions they designed two experiments. These experiments became the basis of the oddball paradigm. In the first experiment the stimuli were binaural tone bursts with frequency of 1000 Hz presented for 50 ms with constant background noise (65 dB). Each of the bursts was either ‘loud’ (90 dB) or ‘soft‘ (70 dB). In between blocks of trials the probability of the stimuli was changing. One type of bursts hade the probability of occurrence of 0.1, 0.5 and 0.9 with the other type having the complementary probability. The participants were instructed to ignore some of the stimuli and attend to other. In the second experiment participants were introduced to two kinds of auditory stimuli, lower tone (with frequency of 1000 Hz) and higher tone (frequency of 1500 Hz) occurring in a random sequence again with the same compatible probabilities.

After examining the results they found out that ignored frequent stimuli only elicited N1 and P2 sensory components. The same was true for a frequent tones that were attended to. However when an ignored stimulus was occurring with less frequently a sharp, late, positive wave was observed, peaking in an interval from 220 to 280 ms. It was labelled P3a to distinguish it from the positive wave (P3b) with later latency that was only observed in conditions that required attention. (Squires et al., 1975)

This paper not only discovered the subcomponents of the P300 but also meant the beginning of the use of oddball paradigm in the evoked potentials research for years to come.

1.3 P3a and P3b

As we have mentioned before in the chapter regarding historical origins of the oddball paradigm the P300 has two subcomponents with differing underlying mechanism called P3a and P3b. At this point we would address them a bit closer.

P3a is elicited by introducing a ‘novel’ type of stimulus. For instance, in auditory oddball it could be adding a buzz or a white noise sound to two clean tones of specific frequencies. Because it is elicited by a ‘novel’ stimulus (a distractor) it was also called a ‘novelty’ P300. Its amplitude usually reaches maximal values at the frontal or central area and it has a shorter latency than the other subcomponent. (Comerchero, Polich; 1999)

When talking about P3a, Polich (2007) reports that P3a can be observed in about 10-15% of healthy young adults. He also states that while using a 3 stimulus oddball task, what he calls a “no-go” P300 is elicited. Polich (2007) mentions that according to some hypotheses it could be linked to inhibition, but it is not yet certain. (Polich, 2007)

P3b is a potential generated as a response to a target stimulus in the oddball paradigm. It has lower amplitude than P3a but it has larger latency. Amplitude of P3b usually reaches maximum in central/parietal regions. (Comerchero, Polich; 1999)

1.4 Context updating theory

One of the theoretical frameworks that are attempting to explain oddball stimuli processing is the context updating theory. According to this model the processing is done on a basis of comparing from the memory if the present stimulus is the same as the last one. If it is not, the state of the system will not change and only sensory evoked potentials will be elicited. However, if the stimulus differs from the last one, the system is updated and in addition to sensory stimuli a P300 (P3b specifically) will be elicited. This model fits very well with what is typically observed in the oddball task. (Polich, 2003)

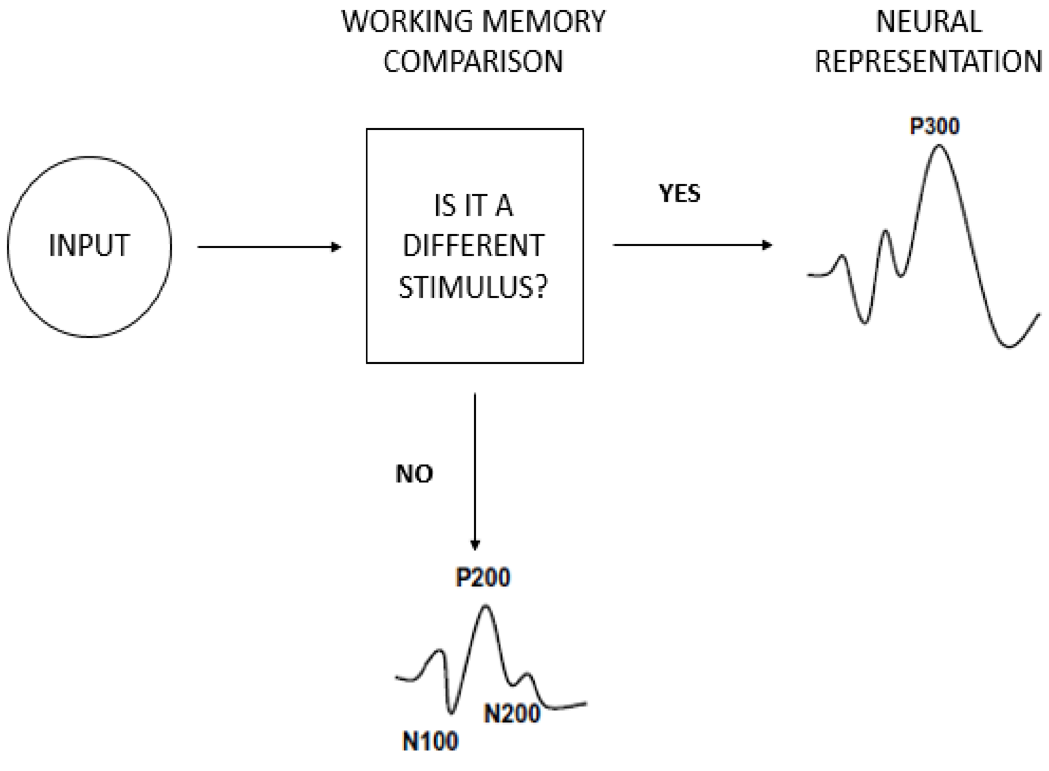

Figure 1: Schema of the context updating theory model according to Polich et al., 2003. This model assumes that the processing of the stimuli takes place as a memory check, comparing the current stimulus with the previous one. If the stimulus is the same, only sensory evoked potentials are elicited (N100, P200, N200), however if the stimulus is different, a P300 (P3b) is also generated in addition to these potential as a result of the stimulus environment being updated.

1.5 Differences in P300 measures

1.5.1 Auditory and Visually elicited P300 differences

Differences between P300 potentials elicited by auditory and visual stimuli are rather well documented. A work by Bennington and Polich (1999) compared P300 measures for active and passive stimuli and found out the passive task yielded smaller amplitudes than the active task, but since we did not use passive task which is used to work with non-compliant subjects (e.g. children, patients with dementia et cetera) this was of no consequence for our purposes. Nevertheless, they theorised that auditory task produces more robust P300. (Bennington, Polich; 1999).

However, a work we already mentioned by Katayama and Polich (1999) used a 3 stimulus oddball with auditory and visual task and found out that both P300 amplitudes were higher and the latencies were longer for visual stimuli. (Katayama, 1999)

1.5.2 Differences between types of responding

Although ERP studies frequently use one of the two traditional types of responding – pressing a button or counting target stimuli mentally, we have not found only one work that would address the differences in performance they may have. Brázdil and collaborators (2003) examined the effects response type on P300 generation and have concluded that peak amplitudes generated by button pressing are significantly higher than those elicited by mentally counting the stimuli. (Brázdil et al., 2003)

1.6 P300 peak detection

In this chapter we will address the methods used to detect peaks in EEG data of event related potentials. There are a few approaches to detecting P300 peaks and we will try to list some of them and review them. For the purpose of locating the P300 amplitudes grand averages of the midline electrodes are used – typically Fz, Cz and Pz, but sometimes including also FCz and CPz electrodes as well. However, as we stated in the chapter about P3a and P3b subcomponents of P300 since P3a attains maximum values centrally and P3b amplitudes are stronger gradually from frontal areas toward parietal, sometimes only one electrode is used. Cz for P3a and Pz for P3b. (Yurgil, Golob; 2013)

The standard way of detecting peaks is looking for a local maximum in a pre-defined interval of latencies. For P300 in general it is approximately 300-550 ms (Squires et al., 1975) but the latencies obtained in different experimental settings tend to differ. Yurgil and Golob (2013) use a range of 250-500 ms. Some authors like Wronka and colleagues (2007) distinguish between early and late P300, which we believe means P3a and P3b in other words and depending on the other conditions would choose interval of approximately 200-400 ms for the early P300s and 350-700 ms for the late P300s. A subclass of this approach could be used as defining P300 as the positive peak following the N1, P2 and N2 components with the highest amplitude. (Elting et al., 2003)

All of the above mentioned methods could be considered conventional. There is however a rather novel method using source analysis. Even though it was not used enough to be able say how consistent and valid results it will provide. It seems, however it will be able to separate temporally overlapping P300 components which would be a great step forward. (Elting et al., 2003).

1.7 Research aim

It has been known for quite some time, that emotion and cognition influence each other and in recent years there were many studies dedicated to this topic. To inspect this relation it would be very interesting to examine how the emotional content in stimuli could influence the way there are cognitively processed. To this day however there has been only few works to focus on the influence of emotion on the P300. The work of Morita and collaborators showed facial drawings showing sadness, pleasure, anger and no emotion to participants while they were undergoing auditory oddball paradigm. The peak amplitudes were smallest for images of pleasure and kept attaining higher values for anger, sadness and no emotion respectively. The latencies were not influenced in the same way, meaning there are probably more independent mechanisms involved. (Morita et al., 2001) Another study was examining differences between schizophrenia patients and healthy controls in recognizing facial emotions and identifying four ERP components – P100, N170, N250 and P300. They did register abnormal values of P300, but their variance was caused by the N170 component. (Turetsky et al., 2007) Last study we mention in regards to dealing with the relation of P300 and emotion is the paper by Jin and colleagues working on new type of P300 brain-computer interface utilizing facial motion and emotional expression. (Jin et al., 2012) There were also a few studies who brought the emotional content into the oddball paradigm. They were addressing ambiguous facial expressions (Neta, et al., 2011), gender differences in processing the valence of the facial expressions (Campanella et al., 2004) or explore the emotion-attention network interaction distribution in the brain (Fichtenholtz et al., 2004). However, these works did not use emotionally charged material as exclusive stimuli in the oddball paradigm. To do so a need would arise for obtaining behavioural data, e.g. presses of the button, for only target stimuli, but also for the standard and distractor stimuli. The reason for this is rooted in the fact that it is not possible to tell beforehand how would the use of emotional material for all stimuli types influence the paradigm and we would need a clear link to participant's registering every stimulus. This would be a new type of responding here referred to as 'respond-to-all'. It is true that the two traditional methods of responding to an oddball task (mental internal counting of the target stimuli and responding to the by pressing a button) give slightly different data, but more importantly both bring certain advantages and disadvantages. The responding by button leaves a very precise behavioural marker to an exact point in time when the reply was made, allowing for knowing exactly if a correct response was made. This approach on the other hand leaves a muscular artefact we have to account for in data analysis. On the other hand the mental counting of stimuli has no muscular activity involved, hence the artefacts are not present, however even after a correct number of target stimuli is reported by the participant at the end of trial it is not sure whether some target stimuli were missed or other non-target stimuli were mistaken for it and there is no marker to be clearly associated with each target stimulus.

Due to these circumstances it is not clear what is the influence of the response type on the final ERPs produced by the oddball task. To examine this we conducted a series of experiments in which participants were subjected to oddball task with 3 types of responding – 'respond-to-target', 'counting' and novel 'respond-to-all' and 2 stimuli of two modalities (auditory and visual) to find out whether the ERPs elicited under different conditions would differ and if so, how.

1.8 Hypotheses

Now we will revise some theoretical findings on which we based our hypotheses. First, we expect responding to every kind of stimulus in the oddball paradigm will make participants perceive distractors a bit more like targets and therefore the p3a amplitudes in distractors should be lower than under commonly used response methods. This same way of reasoning then leads us to believe that the P300 (P3b) in targets should have smaller amplitudes than under traditional types of responding and vice versa distractors should elicit more of P300 peaks with higher amplitudes. Therefore our main research hypothesis stands as:

1. 'Response-to-all' type of responding will differ from the traditionally used methods in amplitudes and latencies significantly.

Since the 'counting' and 'response-to-target' types of responses are commonly used in oddball according to the needs of the researcher one would assume they would perform similarly. To our knowledge the only study to examine and compare these two methods is the one we mentioned earlier. Thus we expect to find similar significant differences in P300 amplitudes (or latencies for that matter). However, as counting silently in one's mind requires the use of phonological loop it is possible that the amplitudes in auditory part of oddball might facilitate the generation of P300 potential resulting in higher amplitudes.

Lastly, regarding latencies, distractor stimuli result in P3a potential that have earlier latency than P3b of targets, which is why we believe that P300s of distractors will have shorter latencies than those of targets. Similarly, it has been widely reported, that potential evoked by auditory stimuli have lower latencies than those generated by visual stimuli and we expect to find this trend in our experiment as well.

The summary of these theoretical assumptions resulted in the following secondary hypotheses:

A. Under the ‘respond-to-all’ condition targets will have slightly lower P300 amplitudes than they would have under usual ‘counting’ or ‘respond-to-target’ conditions.
B. Under the ‘respond-to-all’ condition distractors will have slightly higher P300 amplitudes than they would have under usual ‘counting’ or ‘respond-to-target’ conditions.
C. Under ‘respond-to-all’ condition distractors will have slightly lower P3a amplitudes than would be usual.
D. Targets and distractors elicited under ‘respond-to-target’ condition will have higher P300 potential than those elicited under ‘counting’ condition.
E. Auditory stimuli will elicit higher amplitudes of P300 in ‘counting’ condition than visual stimuli.
F. Under all condition the latencies of distractor stimuli will be shorter than latencies of targets.
G. Auditory stimuli will have shorter latencies than visual stimuli.

2 Methods

2.1 Participants

Our sample consisted of 28 students of cognitive science and psychology study programs of University of Ljubljana (9 male, 19 female) with an average age of 21,4 (SD 4,04; range 18-39). Twenty-six of them were right-handed and 2 had a dominant left hand. We have decided to leave them in our sample since the phenomenon we are studying is not lateralized and hence the left-handedness should have no impact on the data. There were however difficulties with some of the recordings of the data due to faulty electrodes or other causes which led to unusable data. We also decided to leave out some participants due to overabundant noise in the data. The final sample consisted of 15 females and 7 males. Their average age was 20.4 (SD 1.94; range 18-25). All participants had normal or corrected-to-normal vision. Before the procedure itself participants were asked a few questions to provide additional information. Apart from age and sex that was input into the script, subjects were asked how many years have they been studying up to that point, about their dominant hand and their eyesight. Since the participants were students they were all compensated and motivated for their participation in the study by receiving study credits. All of the participant have been informed of the full extent of procedure beforehand and have signed an informed consent.

2.2 Procedure

In our version of response oddball task both visual and auditory stimuli were used as well as three types of responding to it. Two of those were commonly used in the past – 'respond-to-target' and 'counting' and a new one we call 'respond-to-all'. In the 'respond-to-target' type of response the participants were asked to react by pressing a button only to the infrequently appearing target stimuli and ignore the frequent standard and infrequent distractor stimuli. Under the 'counting' condition the subjects were asked to silently count in their mind the target stimuli and at the end of the run to give a total number of targets they noticed. Again, they were instructed to pay no attention to standards or distractors. In the last type of responding we used – 'respond-to-all', where participants were asked to react to target stimuli by pressing a button, but also to react to standards and distractors by pressing another button. The combination of two types of stimuli (auditory and visual) and three types of responding meant we had 6 possible combinations to test out. These comprised the six blocks of trials we used. The experimental procedure was designed as a PsychoPy script. PsychoPy is a freeware program that was developed in the University of Nottingham made for preparing and conducting psychological experiments. It offers a User Interface for easy work, but also allows for use of scripts written in Python to create experiments as the name of the program suggests. Participants were assigned a group number between 1 and 5 at random. These five groups represented pseudo-randomized presets of the order of the trial blocks.

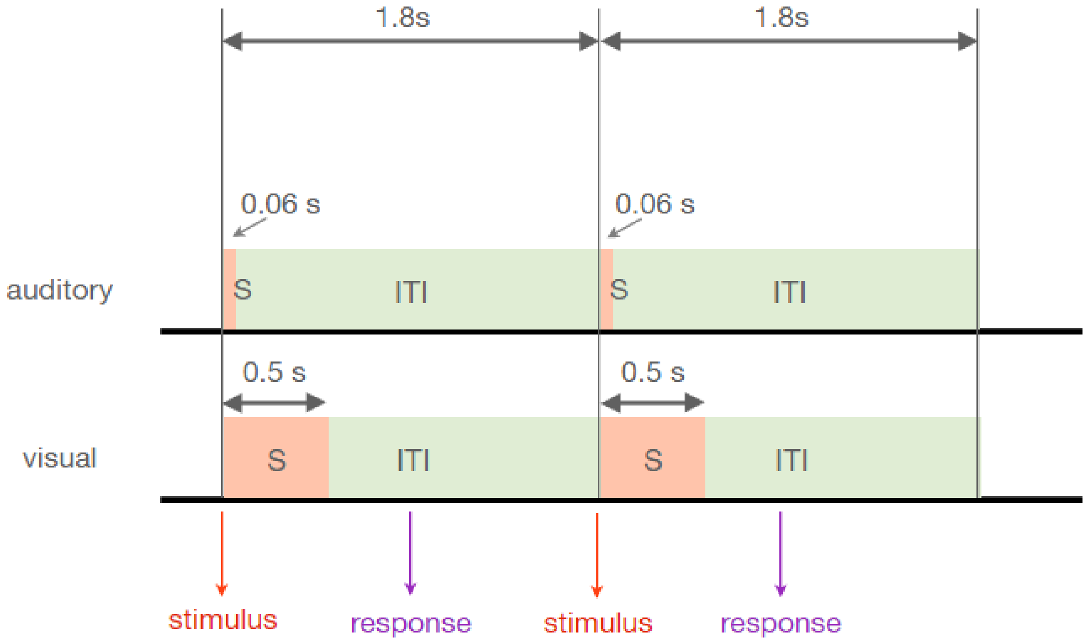

Figure 2: Schematic representation of the trial. Every trial had the same ITI (inter trial interval) of 1.8 seconds. In our case it also served as inter stimulus interval. It always began with presentation of a stimulus, offset of auditory stimuli was 60 ms and for visual it was 500 ms. The rest of the interval also framed the time window for a response.

Each individual trial had ITI (inter trial interval, i.e. the time window between to trials) of 1.8 seconds. In our case the ITI was also time between two stimuli. At the beginning of each trial stimuli were presented – auditory stimuli had an offset time of 60 ms and the visual stimuli were presented for 500 ms. The rest of the ITI was reserved for participants' response if they were required to.

2.3 Stimuli

Our experimental design involves both auditory and visual conditions. These are the *standard* stimulus that is the most frequently occurring one, that participants do not react to, a *target* stimulus which is the infrequent one the subject are focusing on and a *distractor* stimulus which also occurs infrequently, but participants should not react to it. For auditory modality, we used sounds lasting 60 ms. The standard was a lower beep at 500 Hz, the target was a higher pitched beep with the frequency of 1000 Hz and the distractor was a white noise. All the sounds had the same intensity.

As for the visual stimuli we didn't use the traditional squares and circles of uniform colour, but more complex images instead. . Each of them was presented within a circle of diameter 200 pixels. The standards were nebula-like smears of colour. Targets were images of people and distractors were pictures of concrete objects both living and un-living other than humans.

In one block there was a total 300 stimuli meaning 100 stimuli were presented per run. From these 300 stimuli there were 240 standards, 40 targets and 40 distractors. The probability of the standard stimulus to occur was 0.75 and the probability of target and distractor stimuli were both 0.125.

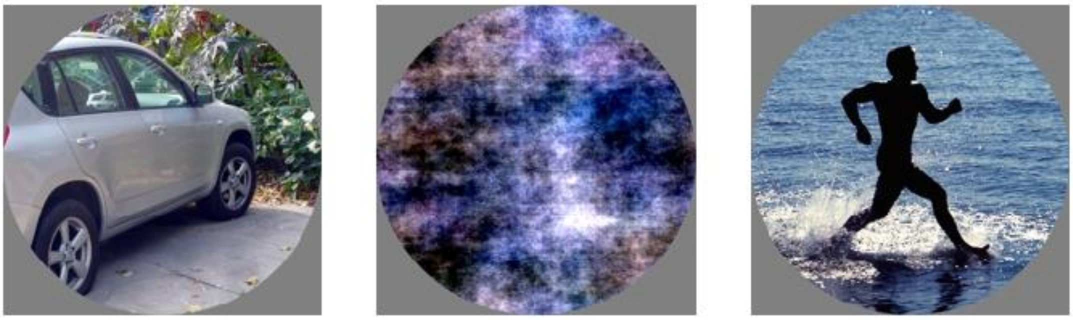

Figure 3: Examples of types of visual stimuli. From left to right: distractor, standard, target. Distractor in an infrequent type of stimulus that does not require a response. Distractor images depicted concrete living and non-living objects other than humans. Standards, frequently occurring stimuli not warranting a response were nebula-like blobs of colour. And the infrequent target stimuli were images of humans or their body parts.

We chose to use these visual images instead of usual stimuli to find out whether the participants would be able to discern the kinds of stimuli based on content only, not relying on the shape. (Conversation with assoc. prof. Grega Repovš, 17. 10. 2016) Although, this would probably merit another research question we decided to not engage it and only work with the influence of response type on P300 potentials.

2.4 Electroencephalography recording

In our experiment we used acti-CAP 64-chanell system with the standard international 10-20 system of electrode placement (see Figure 3). Electrode AFz has been used as the Ground and electrode FCz has been used as Reference, but afterwards re-referenced to the averaged reference.

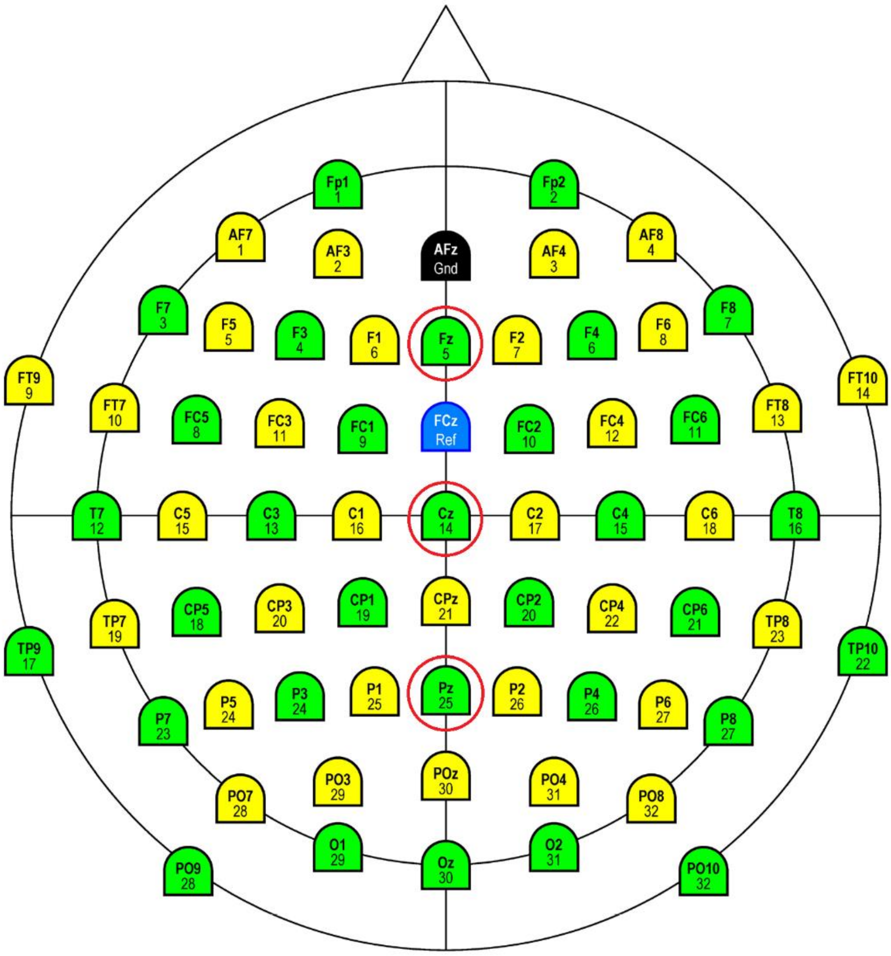

Figure 4: Schematic view of electrode montage. We used the standard international 10-20 system. For the purpose of this theses, in the subsequent analysis, we focused on 5 electrodes from the mid-line: Fz, Cz, and Pz.

We utilized two cap sizes – 54 for female subjects and 58 for male subjects. After the cap was put on the participant we used abrasive gel on the Ground and Reference electrodes and they were then filled with electrolytic gel and scalp was gently scratched. The same procedure was then done for all remaining electrodes with the exception of the abrasive gel not being used on the other electrodes. Those were only gelled and the scalp was scratched gently. For the recording itself we used BrainVision software.

2.5 Experimental set-up

Participants sat in a comfortable chair in front of a monitor in a dimmed, sound attenuating room. The chair, monitor and speakers were at fixed positions at all times and the volume was always kept at the same level. For button pressing purposes a Cedrus board was used. A camera was used to observe the participant and the progress of the procedure to avoid disturbing the participant. Contact was maintained during breaks between blocks and runs via intercom.

2.6 EEG data pre-processing

The pre-processing of the raw data was performed in BrainVision Analyser - the professional commercial software for EEG analysis. Data were first visually inspected any data containing noise caused by non-physiological artefacts were manually removed. In the next step, ICA was used to identify and correct the artefacts caused by horizontal and vertical eye movements (HEOG and VEOG) and by muscle activity (EMG) artefacts. Afterwards, the data were high pass filtered at 0.1 Hz and low pass filter at 60 Hz. Additional notch filter at 50 Hz was used to correct noise from electrical power.

2.7 Data analysis and peak localization

With the data pre-processed we moved to analysis which in our case meant finding the event-related potentials, i.e. the peaks in amplitude. After visually examined the data on the three aforementioned midline electrodes (Fz, Cz, Pz) we meant to use for analysis in the first place we decided that we would use only one electrode to find the maximal value of a peak. We decided it would be electrode Cz for finding p3a and Pz electrode for p3b as these subcomponents are set to attain maximal values around those regions of cortex. Event-related potentials were baselined in the interval from -200 to 0 ms For the purposes of peak detection we used ERPlab a component of EEGlab which is a free Matlab toolbox.

The approach we selected worked with the P300 (p3b) in target stimuli, however we were unable to consistently find p3a potential for distractors on Cz electrode. At this point we had to change our approach and since even the distractors seemed to attain maximal peak values at Pz electrode we decided to look only for P300 potentials in both cases. We took into account the differences in latencies of P300 with regard to the type of stimuli and decided that we would look for P300 as a maximum peak value in the latencies between 200 ms and 600 ms on Pz electrode.

To illustrate this we chose to show EEG scalp maps of one of the participants for target and distractor stimuli across the interval we used to locate peaks, showing immediate peaks every 50 ms of its duration.

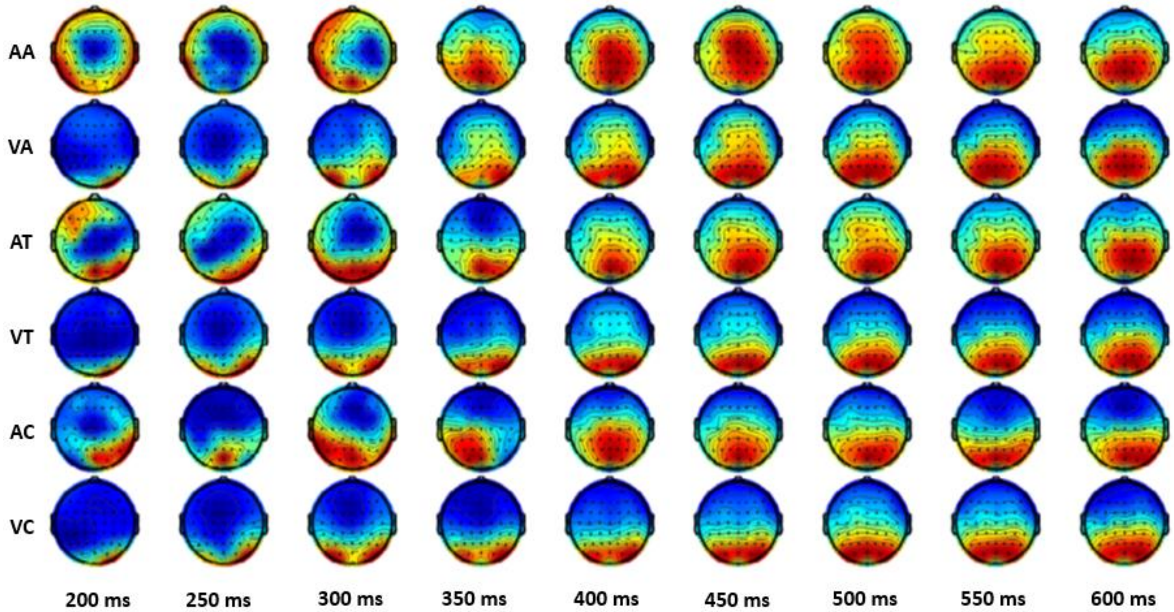

Figure 5*: ERP scalp maps for target stimuli of one participant. Amplitude is coded by colour – blue meaning more negative, red represents positive values. Relatively clearly visible is that maximal peak amplitudes are over the electrode Pz and that peak latencies are shorter for the auditory stimuli compared to the visual.*

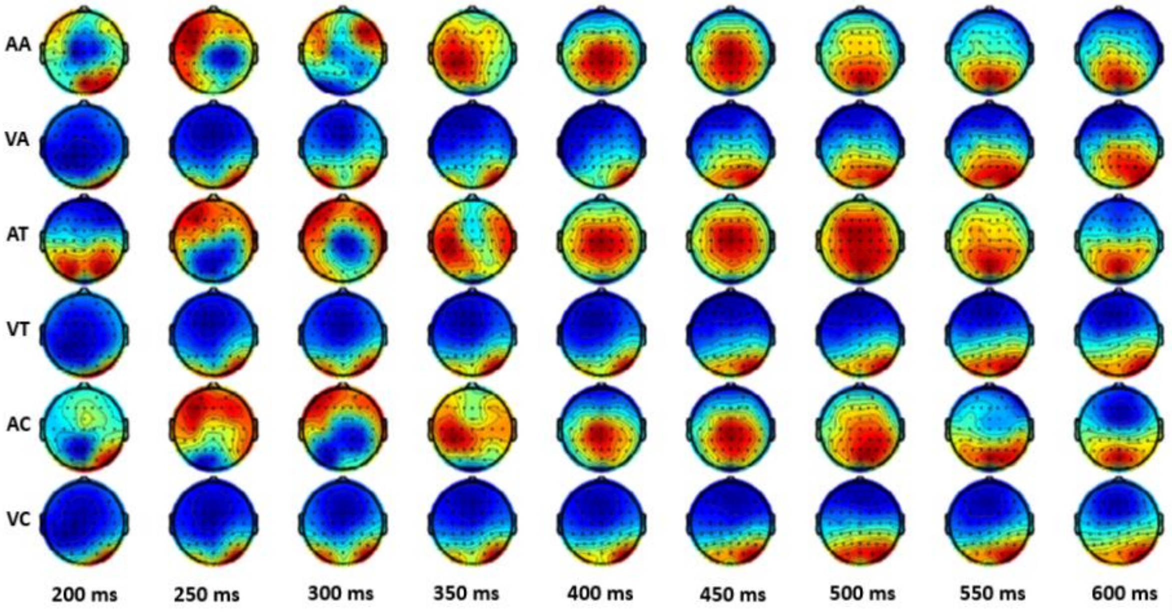

Figure 6*: ERP scalp maps for distractor stimuli of one participant. Amplitude is coded by colour – blue meaning more negative, red represents positive values. Very similar positioning of maximal peak amplitudes close to the Pz electrode, however the peaks seem to be a bit closer to the Cz electrode than the ones elicited by the targets. The shorter peak latencies for auditory stimuli is again present.*

2.8 Statistical analysis

When we obtained the final P300 amplitudes and their corresponding latencies we tested the data with Repeated Measures ANOVA (3x2x2) with factors of Response Type (3 level – *'respond-to-all'*, *'respond-to-target'* and *counting*), Stimulus Type (2 level – *target* and *distractor*) and Modality (2 level – *auditory* and *visual*). The specific factors of the significant effects are given in the Results section. Significant level was set at 0.05 for all analyses. When reporting means we used standard deviation as a measure of variability.

3 Results

Upon analysing the data we have found several statistically significant effects and interactions. There was a statistically highly significant effect of *Stimulus Type* on amplitude of the P300 ($F(1, 21) = 42.530$, $p<0.005$). Mean peaks generated by target stimuli (10.01 ± 4.504 μV) differed from those generated by distractors (7.54 ± 3.029 μV). Other significant effect of the Stimulus Type ($F(1, 21) = 4.635$, $p<0.05$) were found in latencies. P300 latencies for targets (434.8 ± 22.64 ms) was considerably shorter than that of distractors' (493.1 ± 32.01 ms).

Next, we have found a statistically significant effect of the factor *Modality* on the peak latencies ($F(1, 21) = 5.245$, $p<0.05$). Peak latencies for auditory trials (487.2 ± 31.60 ms) were slightly lower than those of visual trials (513.1 ± 40.67 ms) which is consistent with findings from other studies, suggesting our data might be valid.

Last statistically highly significant effect found was the one *Response Type* had on the peak amplitude ($F(2,42) = 9.886$, $p<0.005$). Peak amplitudes for 'respond-to-all' were highest (9.31 ± 4.417 μV) followed closely by 'respond-to-target' (9.12 ± 3.753 μV) and the 'counting' type of response had the lowest peak amplitudes (7.90 ± 3.290 μV). Similar results, stating that mental counting of stimuli generates smaller peak amplitudes then button pressing was found also by Brázdil and colleagues (2003).

Now we will move to significant interactions. There were a highly significant interaction of factors *Stimulus Type x Modality* in both amplitude and latency. For amplitudes ($F(1, 21) = 79.260$, $p<0.005$) targets in auditory task (9.12 ± 4.658 μV) had slightly lower amplitudes than targets in visual task (10.91 ± 4.604 μV) and targets in general had larger amplitudes than both distractors in auditory (8.85 ± 3.664 μV) or visual (6.23 ± 3.015 μV) task. For latencies auditory targets (506.9 ± 32.67 μV) were only marginally smaller than video targets (507.6 ± 48.41 μV). Auditory distractors (467.5 ± 44.16 μV) had shorter latencies than both targets and visual distractors (518.6 ± 44.44 μV) which is as we would expect, however the higher value for visual distractors is unusual.

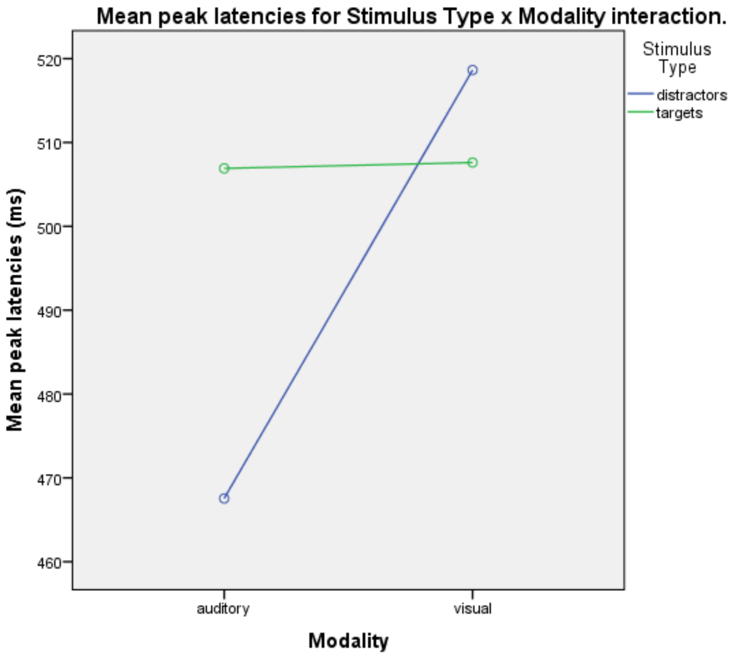

Figure 10*: Mean peak latencies for Stimulus Type x Modality interaction. While latencies of target stimuli are mostly not influenced by the modality, the distractors show a strong dependency on it.*

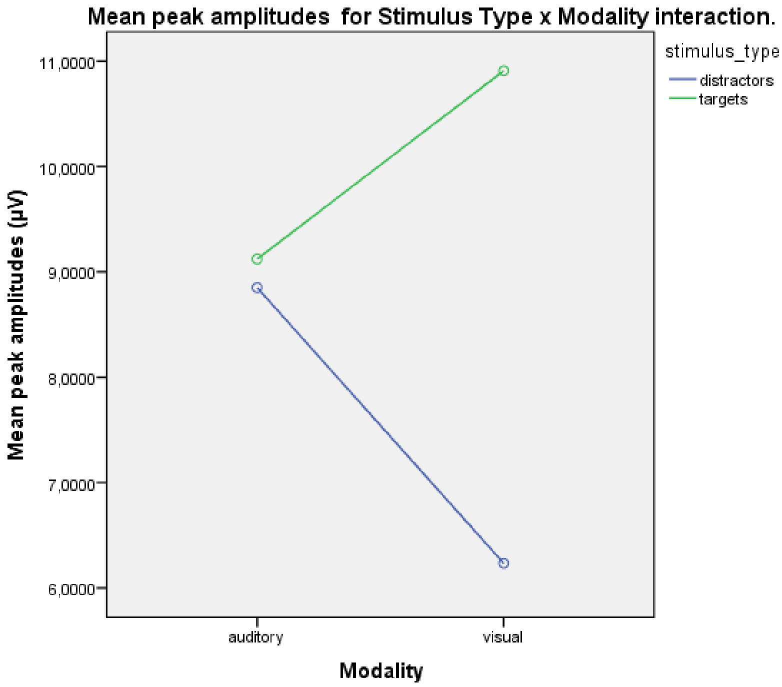

Figure 11*: Mean peak amplitudes for Stimulus Type x Modality interaction. Targets and distractors reached similar latencies in the auditory tasks, but differed greatly in the visual.*

The highly significant interaction *Stimulus Type x Response Type* ($F(2, 42) = 9.146$, $p<0.005$) was found for amplitudes. Target stimuli had larger mean peak amplitudes on the whole compared to distractors. Precise numbers are as follows: targets for 'respond-to-all' (10.0 ± 4.95 μV), targets for 'respond-to-target' (10.9 ± 4.95 μV) and targets for 'counting' (9.1 ±4.01 μV), distractors for 'respond-to-all' (8.6 ±4.01 μV), distractors for 'respond-to-target' (7.4 ± 2.70 μV), distractors for 'counting' (6.7 ± 2.75 μV).

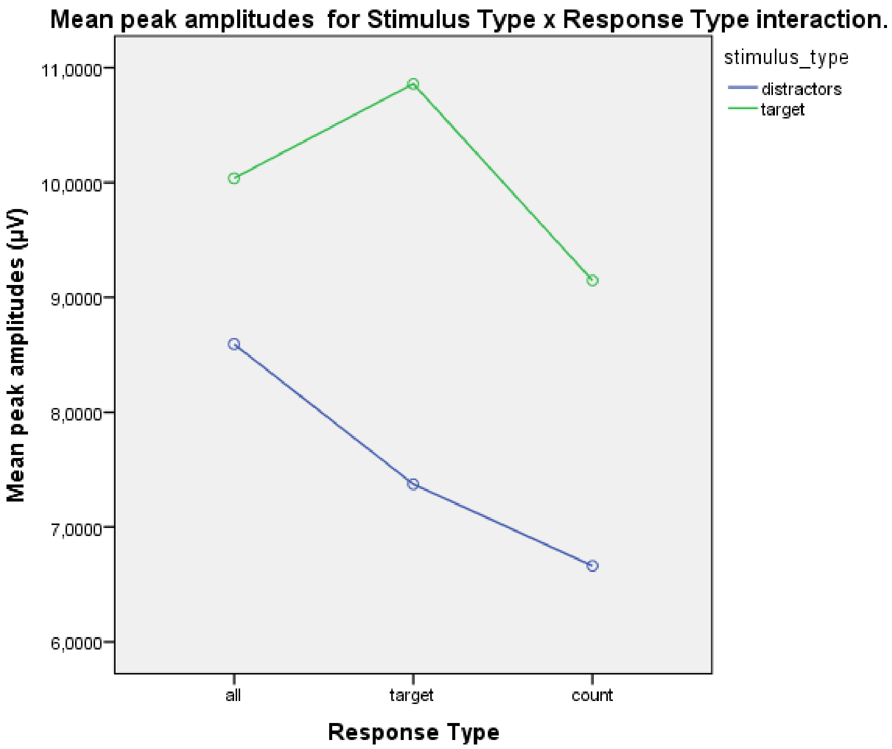

Figure 12*: Mean peak amplitudes for Stimulus Type x Response Type interaction. We can observe that targets elicited peak with higher amplitudes than distractors under every type of responding. The target peak amplitudes were largest for 'respond-to-target' response type and 'counting' had the lowest amplitudes for both targets and distractors.*

The last interaction *Modality x Response Type* we found was also statistically highly significant ($F(2, 42) = 9.528$, $p<0.005$). For the auditory the mean peaks were:

‘respond-to-all’ (9.0 ± 4.64 μV), ‘respond-to-target’ (9.5 ± 4.44 μV), ‘counting’ (8.5 ± 3.43 μV); and for visual: ‘respond-to-all’ (9.7 ± 4.48 μV), ‘respond-to-target’ (8.7 ± 3.60 μV), ‘counting’ (7.3 ± 3.56 μV).

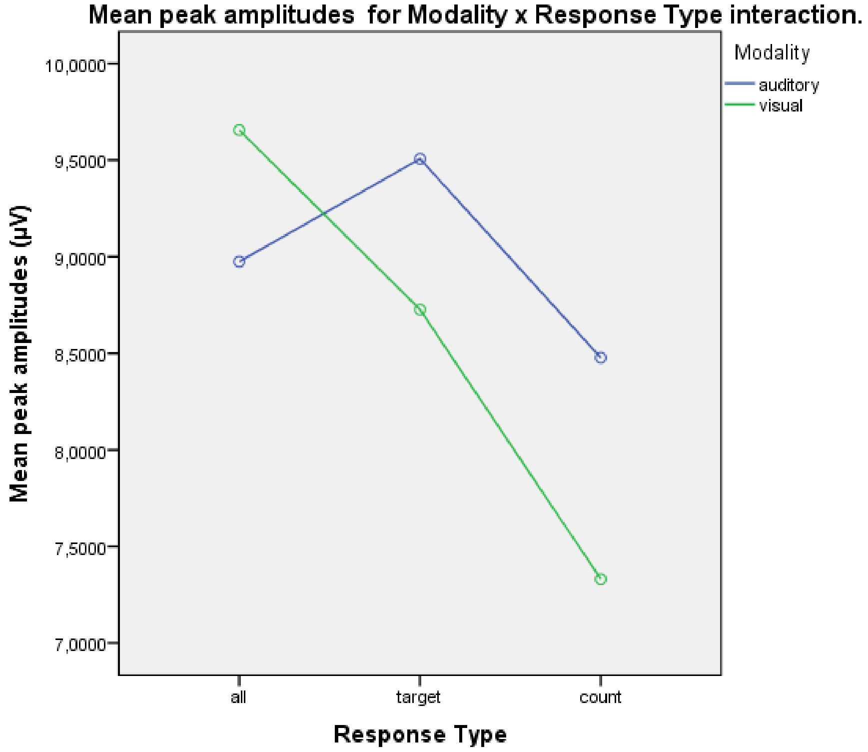

Figure 13:*Mean peak amplitudes for Modality x Response Type interaction.*

4 Discussion

Our main research question was whether the new way of responding (pressing of a button for targets and pressing a different button for non-target stimuli) will or will not change the results of the oddball task. We anticipated that it will not influence them fundamentally so our null hypothesis was that 'respond-to-all' (pressing a button to target stimuli and another button to non-target stimuli) type of responding will not differ from the two other commonly used types of responding (pressing a button to target stimuli and mental counting of target stimuli). The only statistically significant effect of the Response Type factor was on peak amplitudes and even though they were significantly larger than those of the other two methods of responding, this effect was only marginal when compared with 'respond-to-target' amplitudes. It does however suggest there is some difference and we believe it would merit more experiments being done on the matter. It does make sense that this new type of responding would influence the P300 peaks. Pressing a button upon perceiving a distractor would in a sense make it a kind of target stimuli, which could mean it would also elicit similar P300-like potentials. According to this same effect however, the mental counting of targets generated lower P300 peak amplitudes than other types of responding we used. This corresponds with results of Brázdil and colleagues (2003) who also compared button pressing and mental counting and concluded that amplitudes for counting were lower. But since we found the same effect, we consider it strange that so little attention is given to such an important factor in all of these studies. On the contrary, methods of responding are often regarded as given and just used to what the researchers need from them and no second thought is given to consequences or to how the results they provide may differ.

In our secondary hypotheses A and B we predicted that while using 'respond-to-all' type of responding the targets would have slightly smaller peak amplitudes and distractors slightly larger amplitudes then they would using other two methods of responding. We reasoned this way because we anticipated that using another button to report all the non-target stimuli would in a sense make the distractor (infrequent non-target) stimuli a sort of 'target' stimuli for that part of task and thus they should elicit a larger peak and in the same way the competition between now two infrequent target stimuli (in these circumstances also counting distractors) would make the target peaks lower which is what was observed. The highly significant interaction of Stimulus Type and Response Type analysis found that the targets amplitude was lower under ‘respond-to-all’ and larger for ‘respond-to-target’ and vice versa for the distractors. Also what came up in this interaction was that for both types of stimuli the mental counting of targets generated the lowest peak amplitudes. We already mentioned that this was reported once by Brázdil and collaborators (2003) but we did not yet address the cause of this. We believe that even though pressing a button produces a motor artefact, the motor action might somehow stimulate the P300 peaks. But that does not answer why the effect is present even for the distractor stimuli. We will revisit this in a moment after we go through some new information.

Regarding our secondary hypothesis C, we expected to find p3a peaks in response to distractors for every type of responding, but we instead found the ‘no-go’ P300 peaks so we could not compare them between each other and we found no significant interaction of Stimulus Type and Response Type factors.

Both infrequent stimuli (targets and distractors) have elicited stronger peak amplitudes for ‘response-to-target’ than counting as predicted by secondary hypothesis D, not only on the whole, but for two modalities separate.

Moving onto other significant effects we found there was an effect of Stimulus Type on the P300 peak amplitude, but since distractor amplitudes were lower than the target amplitudes we believe that what we observed for distractors were not the p3a peaks that should have larger amplitudes than p3b component elicited by the target, have fronto-centrally located maximum peak amplitudes and also should a shorter latency (Comerchero, Polich; 2007) which was another effect of Stimulus Type we found that was reversed. Based on these results we think it may have been the ‘no-go’ P300 that Polich (2007) mentions in his paper. As to why does ‘no-go’ P300 have smaller amplitudes and longer latencies than p3b? We do not know. One possible explanation is that it is indeed link to inhibitory processes which could probably account for was observed in our data. The longer latencies for distractor stimuli however contradict our secondary hypothesis F.

Now we would go back to the question why the peak amplitudes for ‘counting’ are lower not only for targets, but also for distractors. If we consider that the P300-like potentials elicited for the distractors are the ‘no-go’ type, then perhaps these are kept somewhat proportional to the P300 of the targets which could explain why their amplitudes also drop when the ones elicited by targets do.

Next effect we found was the one Modality had on peak latencies. Auditory stimuli had significantly shorter latencies that visual stimuli. Explanation for this effect probably lies in the fact that it takes less time for auditory signal to reach primary auditory cortex than it takes for the visual stimuli to reach the primary visual. It is also consistent with work of other authors who also reported shorter latencies for auditory oddball when compared with visual, such as the work of Katayama and Polich (1999) and also consistent with our secondary hypothesis G.

Another significant interaction of Stimulus Type and Modality was present for both amplitudes and latency. The results we obtained here were mostly consistent with our other findings. The amplitudes for targets were larger for the visual part of the task compared with the auditory part as would be expected like we mentioned earlier. However this was reversed for the distractors which is a little odd. Perhaps it was caused by the choice of visual stimuli, it would probably merit more examination with different images used for visual distractors. We used a set of images of concrete non-living and living objects other than humans that varied a lot and while it seems differentiating targets and distractors by content alone is indeed possible, since our subjects succeeded in that, the nature of some of these distractors was perhaps such, that we obtained these results.

The peak latencies from both types of stimuli were also shorter for auditory task, but the target latencies for auditory modality were nearly the same as those for visual, only being marginally shorter. In this matter the effect was much more prevalent in the distractors with the difference being almost the same as the one we described in the general Stimulus Type effect.

Last interaction we would like to mention is the Modality x Response Type. The mean peak amplitudes by modality varied highly significantly for each response type.

We again find a difference between the ‘respond-to-all’ and the other types of responding in peak amplitudes across both modalities. The ‘respond-to-all’ had larger amplitudes than ‘respond-to-target’ in visual parts of task and smaller amplitudes in auditory. The ‘counting’ type of responding had the lowest amplitudes for both sensory modalities we tested. This once again shows us that there are differences between not only two traditionally ways of responding, which in itself is an important and often overlooked fact, but also the new way of responding by pressing a button to every stimulus generates peaks of different amplitudes. And considering modality differences in mental counting response, the auditory part generated larger amplitudes than the visual which was consistent with our hypothesis E. This could be due to our theorized effect of use of phonological loop while keeping the total of the target stimuli in mind, but we do not have the data to say this conclusively.

To summarize, the new method of responding to oddball task we tested does perform differently than the other two, however we believe that the results it provides are not so fundamentally different from the other methods that it would change the principle of the oddball task, so we conclude it can be used in the emotional oddball experiment, but would benefit from further examination before it is used for that purpose.

5 Limitations

We are aware of some limitations our study might have had and we are going to address them here. First of all, it was a rather small number of participants which is however quite common for these kinds of studies. Other was a large number of faulty electrodes we encountered which made the preparation difficult and time-consuming. None of the electrodes we used for the analysis was malfunctioning luckily. Unfortunately, a small part of participants had to be excluded from the sample because of noisy data or some error during recording.

Conclusion

The aim of our study was to determine how the method of responding to the oddball task influences the P300 evoked potential. For this purpose we tested our experimental design to compare three methods of responding to the oddball. Reacting by pressing a button for the target stimuli, mentally counting the targets and a new method, we proposed for the future purpose of emotional oddball, pressing a button for target stimuli and pressing another button for standards and distractors. We decided to test this out on two modalities – auditory and visual. We had a main hypothesis regarding the outcome of our experiment, theorizing that the ‘respond-to-all’ method might yield different results than the other methods. Upon executing the experiment we analysed the data from 22 participants. We have found three statistically significant effects and three statistically significant interactions, of which most important to our main research question was the effect of Response Type factor on the peak amplitudes. This means that all three different methods of responding to oddball task differ in the peak amplitudes among each other. Of course the question remains whether the new type of response we tested can be used in the emotional oddball? We believe that it might be used, even though it generates slightly different peak amplitudes that the other two methods, because it does not deviate from other in fundamental attributes. There are however some minor differences in peak amplitudes of targets and distractors which may require some more experiments conducted on the matter.

Regarding Response Type we also found that mental counting of target stimuli produced smaller peak amplitudes under both modality conditions that both types of responding by pressing a button. This is not usually mentioned in the studies that decided to use either of them and it might be part of some scientific tradition, but we feel these differences should be noted and researched if we plan on using one of those methods of responding based on what results we want to obtain, so that we know why that happens.

Other notable differences were found between modalities. We expected to find, that auditory peak amplitudes and peak latencies would both have smaller values than the visual ones. This was true only for latencies as they were significantly shorter for auditory stimuli. The peak amplitudes of the visual parts of the task were however larger for the target stimuli, but not for the distractors. Most of these findings were consistent with previous research suggesting that our procedures and the data it produced was rather valid.

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