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מוגש על-ידי:

יעל גרא

ת.ז 204120430

מנחה:

פרופסור מיכל בן-שחר

המחלקה לבלשנות וספרות אנגלית

והמרכז הרב תחומי לחקר המוח

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Thesis Proposal for a Masters Degree

Sensitivity of Microsaccades to Morphological Structure of Spoken Hebrew Words

Submitted by:
Yael Gera
ID 204120430

Advisor:
Prof. Michal Ben-Shachar
Department of English Literature and Linguistics
and The Gonda Brain Research Center
Bar Ilan University

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0. Abstract

Mapping words onto the mental lexicon is a necessary process in order to understand and use a language. Morphology holds a great deal of information about a word and we rely heavily upon it to understand the meaning of single words (Rastle, 2019). Although well researched, many questions regarding the nature of morphological processing are still left unanswered. While most of the research focused on the properties of visual word recognition, a further investigation that concerns other modalities is needed to deepen and generalize our understanding of this process. This research will approach this topic by examining the morphological interference effect (MIE) in the auditory domain, using microsaccades as the dependent measure. In a prior study by Yablonski et al. (2017), microsaccades were shown to be sensitive to the MIE for visually presented words. In this research, we will investigate the sensitivity of microsaccades to auditory MIE in order to generalize the effect across modalities. Furthermore, we will assess the contribution of executive functions, assessed via the Bivalent Shape Task (BST), for explaining the MIE observed in individual differences. Preliminary results from three participants suggest that microsaccade inhibition may be sensitive to the MIE, even when words are presented in spoken form. The results of this study can contribute to the understanding of how words are stored in the mental lexicon and how we process language. The purpose of this line of work is eventually to be able to measure morphological sensitivity in other populations, such as children and populations with learning disabilities.

1. Introduction

Morphology is an important aspect of language processing. Referring to the different morpheme components of the word allows us to process a complex word faster and in a more efficient way by accessing the meaning of these morphemes (Rastle, 2019; Rastle & Davis, 2008). A large body of research has focused on the processing of visual words in reading, in an attempt to create a model of complex word recognition. The morpheme interference effect supports the notion of morphological decomposition by showing a sensitivity to the word structure. That sensitivity appears in longer reaction times and more errors to pseudowords that contain a real morpheme (e.g., *dejuvenate*) as compared to pseudowords that contain an invented morpheme (e.g., *depertoire*). This established phenomenon in the morphological decomposition account is known as the morpheme interefence effect (MIE). Although an integral part of language processing, many questioned are still unanswered regarding the processing of a spoken word. This study will examine the MIE and its influence on the microsaccades rate in a spoken word paradigm. This research is an attempt to replicate a previous study that showed a microsaccade sensitivity to visual word detection in a lexical decision task (Yablonski et al., 2017). The effect of morphological structure will be tested through the microsaccades rate and the differences in the inhibition between invented-root pseudowords and real-root pseudowords. The goal of this study is to generalize the sensitivity of microsaccade to MIE to other modalities.

This research is a step towards understanding morphological processing, and specifically, this is a chance to look into spoken word processing in Hebrew using an indirect measure of miniature eye movements. If microsaccades turn out to provide sufficient sensitivity to morphological processes applied to spoken words, we can harness this tool to study morphological processing among young children, illiterate, or learning disabled populations.

2. Literature Review

2.1. Morphological processing

Morphology studies the internal structure of words and their structural units, morphemes. Morphemes are defined as the smallest, meaningful piece of a word that has a grammatical function (Aronoff & Fudeman, 2011). The study of morphological processing in psycholinguistics started with two dominant competing models that characterize differently the way complex words are stored in the mental lexicon. Supralexical models regard the word as a whole unit. In that case, complex words (words that are formed from a stem and an affix) would be treated the same way as simple words (Manelis & Tharp, 1977). This model claims that words that are constructed from a stem (e.g., FOAM) and an affix (e.g., -y) are processed similarly to words that cannot be lexically taken apart (e.g., DANDY). On the other hand, sublexical, or decompositional, models, take into account a morphological decomposition and first describe access to the morphological components of the word before lexical access (Taft & Forster, 1975). The research that supports these models was conducted within domain of derivational morphology. Derivational and inflectional morphology are two distinct subfields in the study of morphological processing. The difference between the two can be found both in syntax and in semantic aspects. Specifically, inflectional morphology concerns morphemes that serve agreement in gender, tense or number. On the other hand, derivational morphemes create new words by combing existing structural units and may also change the lexical category and the meaning of the word (Miceli & Caramazza, 1988). A growing body of research supports the decompositional model in both domains (Amenta & Crepaldi, 2012). The current study is derived from the decompositional model and will examine the sensitivity to derivational morphemes measuring miniature eye movements, better known as microsaccades.

2.2. Morpheme interference effect as an index to morphological sensitivity

The morpheme interference effect (MIE) is a phenomenon that was found to support the morphological decomposition account, both for derivational affixes (Deutsch & Meir, 2011; Plag & Baayen, 2009; Taft &

Forster, 1975) and inflectional affixes (Miceli & Caramazza, 1988). Taft and Forster (1975) showed that participants took an extended amount of time to decide if a pseudoword is real or not when it was constructed from a real stem rather than an invented stem (dejuvinate - *juvinate* versus depertoire - *pertoire*). These results support the idea that we decompose a word into morphemes before we access the lexicon (Crepaldi et al., 2010, 2013, 2016). In a lexical decision task that compared error rates and reaction times between pseudowords consisting of a real root compared to pseudowords consisting of an invented root, higher reaction times, and lower accuracy rates were found for the real root condition (Yablonski & Ben-Shachar, 2016). Differences in the dependent variable are expected in the current study as well. Due to the different lexical activation patterns that are assumed to occur as a dependency of the pseudowords structure, differences in eye movements are expected in the real root pseudowords as compared to the invented root pseudowords.

Morphological processing has been studied in the visual domain as well as in the auditory field. Much of the research is focused on studying morphological processing in the context of visual word recognition (Bertram et al., 2000; Crepaldi et al., 2010; Longtin & Meunier, 2005; Miceli & Caramazza, 1988; Yablonski & Ben-Shachar, 2016). For instance, the position of the morphemes was found to have a significant role in lexical activation of written words (Crepaldi et al., 2010). Morphological processing was also studied in the auditory domain. Specifically, morphologically priming was found in the auditory domain for primes that rhyme with the stem of the word (Bacovcina et al., 2017), primes that share a root or pattern (Ussishkin et al., 2015) and semantic transparency (Longtin et al., 2003) were found to facilitate performance on lexical decision tasks. The interest of the current study is to investigate the sensitivity to word structure in a spoken word detection task via the morpheme interference effect. We will compare two pseudoword conditions (real root and invented root) to see if pseudowords that comprise of a real root cause a lower rate of microsaccades movement as a result of the morpheme interference. Further to the contribution to the understanding of the extent of the MIE in Hebrew and its' effect on microsaccade eye movements, this research will focus not on visual word detection, but auditory detection. The results of the research might hint on the similarities or the dissimilarities that auditory and visual word recognition processes have in common. If an effect is found in a spoken word detection task, it will allow us to use this paradigm with populations that have limited reading abilities, such as children and populations with learning disabilities.

2.3. Morphological processing in Hebrew and the Hebrew MIE

Hebrew is a compelling case for studying morphological decomposition. As opposed to languages such as English, most Hebrew words are multimorphemic, and morphological derivation takes place in a non-linear fashion. The triconsonantal root is embedded in a phonological pattern, comprising of 2 nonsequential vowels (e.g., KeTeR, a crown) or a combination of vowels and consonants (hiXTiT, to crown). The predefined patterns allow forming different meanings with the same root, thus creating a productive morphological system (Frost et al., 1997). Sensitivity to morphological structure seems to uphold its effect in Semitic languages similar to European languages, with enhanced sensitivity to the root morpheme (Velan & Frost, 2011). An effect was observed in various tasks of visual word recognition where speakers were showing evidence of extracting the root from written or spoken words (Deutsch et al., 2000; Frost et al., 1997; Velan & Frost, 2011). This effect was found in both verbal and nominal domains (Yablonski & Ben-Shachar, 2016). Furthermore, children as young as second graders showed the existence of root awareness, as well as more errors when the distracter shared the same root as the target (Ravid & Schiff, 2006). These results stand at the base of this research of root sensitivity among adult readers.

2.4. Microsaccades as a cognitive measurement

Our eyes are presented with scenery that is continuously moving and changing. Constant eye movements are necessary to keep in foveal vision the objects that we focus on, while miniature eye movements function to refresh the projection of the image on the retina (Martinez-Conde et al., 2004; Rucci & Desbordes, 2003). Microsaccades are among the three fixational eye movements, alongside tremor and drift (Martinez-Conde et al., 2006). They are ballistic movements that occur once to two times each second when fixating on a stationary visual target (Engbert & Kliegl, 2003b; Winterson & Collewin, 1976). These small eye movements cannot be voluntarily produced and thus cannot be controlled or anticipated by the subjects (Martinez-Conde et al., 2006). This notion gives the current research advantage over others that use reaction time as a dependent variable. Eye movements are considered an implicit variable that lets us bypass the awareness of the participants, which might influence their reaction during tasks.

Studies have shown that a decrease in microsaccadic rate (also, msRT) indicates changes in stimuli characteristics. For example, luminance, color, and modality of the stimulus were found to influence differently on the duration and magnitude of the msRT, which indicate longer and stronger inhibition (Rolfs et al., 2008). Moreover, microsaccades show an inhibition and a bounce-back effect during a visual oddball paradigm (Valsecchi et al., 2007). When displaying a rare stimulus that is presented between standard stimuli, microsaccades inhibition was observed immediately after the stimulus, and afterward, an increase of rate occurred, before returning to the baseline rate. Nevertheless, most of the studies that focused on the sensitivity of microsaccades used a low-level of a visual or auditory sensory target. With that said, some complex or higher cognitive demanding tasks were found to affect msRT as well. Mental arithmetic (Gao et al., 2015; Siegenthaler et al., 2014) and internally directed cognition (Benedek et al., 2017) have been indicated to influence the msRT. MsRT was found to be influenced by word structure as well. Yablonski et al. (2017) showed in a written word experiment, that real-word similarity modulated msRT and that pseudowords that contained a real root produced greater inhibition and a greater bounce afterward (as compared to pseudowords that were comprised of an invented root). Their research established that msRT is sensitive to MIE, similar to what was found in tasks that measured participants' reaction time. We used the term msMIE to refer to the MIE measured using microsaccades. This study examines the msMIE using auditory stimuli for the first time.

2.5. Microsaccade inhibition during auditory stimuli

Using an oddball stimuli is a frequent paradigm when showing a microsaccade sensitivity to auditory presents stimuli, as was observed in visual stimuli (Valsecchi & Turatto, 2009). The prolonged inhibition in msRT (before the accelerated rate prior to the return to baseline) regardless of the modality (visual versus auditory) might indicate a connection between the system that's responsible for generating microsaccades and the auditory system. Further research has shown the existence of a simple categorization in an oddball paradigm, as was seen in the differences of msRT. Also, msRT was found to be sensitive to the target's and distractor's characteristics when they were different in intensity and pitch (Widmann et al., 2014). Furthermore, the change in msRT was observed as early as 142 ms after stimulus onset. Although the stimuli that are being used in the current research require a higher level of function, we expect to see an almost instant change of msRT in response to all pseudoword conditions, but a lower microsaccadic rate in response to the real-root condition.

Another point of interest is the time of inhibition. As opposed to the short and simple stimuli that were used previously, the time point of the recognition of a word (where we observe msRT inhibition) can be affected by a few things as a result of its complexity. We will focus mainly on the uniqueness point (UP). The UP is the point in a word that it's fully distinct from any other word in the lexicon (Luce, 1986). In a lexical decision task, that point is the point that a non-word can be rejected as a pseudoword. The UP seems to influence both visual word recognition (Kwantes & Mewhort, 1999; Lindell et al., 2003) as well as auditory word recognition (Balling & Baayen, 2008; Radeau et al., 1989). Furthermore, Radeau et al. (1989) found that manipulating the UP affected the reaction time in gender classification task (RT latencies occurred with a later UP). Radeau and Morais (1990) used in their study the same set of stimuli in a shadowing task and found that an early UP had a greater effect than a later UP. This research is aimed to investigate the sensitivity to word structure as will be seen in microsaccades rate and ultimately, to see whether the effect that was observed in visual word processing can be replicated to the auditory modality.

2.6. Assessing the contribution of executive function to the MIE

One of the questions that will be examined in the current research is whether there are individual differences in executive functions that could explain the different responses to the MIE. Executive functions (EFs) have become the focus of much research in the linguistics domain in the last decade or so. Executive functions can be divided into three intertwined, yet independent components: Inhibition, working memory, and cognitive flexibility (Diamond, 2006). These abilities were said to underline our ability to accommodate relatively quickly to a change of environment and, at the same time, inhibit behaviors that are not suited (Jurado & Rosselli, 2007). EF abilities play a role in language comprehension (Gemsbacher & Robertson, 1999; Green & Abutalebi, 2013) and word production (Bialystok & Feng, 2009; Kroll et al., 2008). EF abilities in the linguistics domain were found to underline the differences between multilingual and monolingual children in different aspects of the language, such as vocabulary (Bialystok & Viswanathan, 2009; Kousaie et al., 2014; Soveri et al., 2011). So far, no research has yet to try and examine the possible connection between morphological sensitivity and EF abilities, and the way the latter might modulate the effect of morpheme interference.

Inhibitory control is a central aspect of EFs (Diamond, 2013). This ability is a top-down process that allows us to select a response to the weaker but relevant aspect of the task, and by that suppressing the reaction of the non-relevant and dominant aspect (Miller & Cohen, 2001). The information gathered from the outside world might present interference to the information collected from the sensory system. The better that we can overcome this interference, the better we can say our executive control is. This particular variable has great relevance to the research because of the nature of the task that is used to examine the effect of morphological interference. In the current experiment, participants are required to press a button only when hearing a real word, and to inhibit their response when hearing a pseudoword that may sound like a real one. A conflict between the two pseudowords conditions exists as well. This conflict is caused by extracting the root, and by that making it harder to define the word as an invented one. We assume that the differences in msRT between the pseudoword conditions can be explained (at least partially) by the differences in the individual cognitive control abilities.

3. Research Questions and Objectives

RQ1: Can we see an influence of MIE on microsaccadic eye movements in the auditory modality? The first objective of the research is to try and generalize the morpheme interference effect on microsaccadic eye-movements to the auditory modality. This effect was already observed in visual word detection (Yablonski et al., 2017), and the purpose of the current research is to try and generalize this effect to the auditory domain.

RQ2: At what time point will the microsaccadic inhibition occur? We will address this question by looking at the time point at which microsaccadic inhibition is being observed. As opposed to visual word recognition, auditory word recognition develops in time, and the time point at which we can identify the root or reject a pseudoword may vary across different stimuli (Gafni et al., 2019; Marslen-Wilson, 1987). Furthermore, the modality of the stimuli makes it possible for the inhibition to occur at proximity to the uniqueness point of each word and thus could hint of the morphological processing of the word. The measurement of the microsaccadic RT allows us to look at different time points during the stimuli presentation and check where we would see the significant change in rate. In the current research, we will focus on 3 time points: stimulus onset, stimulus offset and the uniqueness point that was calculated for each word (in milliseconds).

RQ3: Is the MIE driven by individual differences in executive functions? The third objective is to assess the relation between individual morphological sensitivity and EF measures. A measurement of interference cost will be calculated via the Bivalent Shape task and will be entered to the analysis. We will quantify the percentage of MIE variance explained by individual differences in EF.

4. Hypotheses

The hypotheses are as follow:

H1: Similar to the observed effect for the visual stimuli, we expect that differences in msRT will be found between the condition of a real root pseudoword and an invented root pseudoword. Moreover, the pattern of inhibition is assumed to be different between the two conditions; in the real root condition, we expect to see greater inhibition (a lower microsaccadic rate at the minimum point) than in the invented root condition. Nevertheless, the expected change in the microsaccadic rate is assumed to be smaller to what was observed in the visual word detection because of the less ambiguity that the modality dictates.

H2: Concerning the second research question, we expect the msMIE to emerge at the uniqueness point. This is the point when the listener has sufficient information to extract the root.

H3: For the third research question, we expect to see a connection between individual differences in interference suppression and the size of the msMIE. The prediction is that participants that have a higher interference cost in the interference assessment task will have more difficulty to reject a real root pseudoword. Individuals who are better in suppressing an irrelevant response will show a smaller msMIE. This is expected to explain part of the variance in msMIE.

5. Methods

5.1. Participants

Participants will be 20 healthy adults (age 18 and above). The inclusion criteria are native Hebrew speakers, right-handed, and intact hearing. Exclusion criteria: learning disabilities of any kind (ADHD, dyslexia, etc.) or history of neurological deficits. Although we use a camera that records eye movements, the inclusion of participants with glasses is possible.

5.2. Stimuli and procedure

Before the beginning of the experiment, all participants are required to fill in a questionnaire that contains SES information, a Hebrew version of the Edinburgh handedness inventory (Oldfield, 1971), a native language questionnaire and a questionnaire about history or existing impairments. After completing the questionnaires, participants will go through the word detection task and the EF task, in that order. Every task, its stimuli and procedure, will be detailed in the following section.

5.2.1. Morpheme interference effect

We will use stimuli developed in a previous study (Gafni et al., 2019). Real words and two types of pseudowords will be presented: real-root pseudowords and invented-root pseudowords. The six patterns that were used to form the nouns were *CaCiC*, *CCiCa*, *CiCuC*, *haCCaCa*, *hitCaCCut*, and *maCCeCa* (example of each pseudoword condition is presented in Table 1 of Appendix A) and the appearance of every pattern in the pseudowords conditions was closely matched (Table 2 of Appendix A). Word stimuli are 4-10 phonemes long (mean 5.87±1.17). Phonological forms of the pseudowords were matches on string length and duration (for more details on stimuli selection see Gafni, Yablonski and Ben-Shachar, 2019). A list of stimuli is presented in Appendix C

Each condition will be sampled by 100 stimuli. Every pseudoword (from the two conditions) will be presented two times and each real word will be presented 4 times (producing a total of 800 trials). A gap of 50 to 70 words is presented between each identical stimuli. The stimuli are divided into 10 blocks (80 stimuli each block), which lasts about 4.5 minutes per block. Every block contains 40 real words, 25 real-root pseudowords and 25 invented-root pseudowords. Stimuli are presented in a pseudorandom order, where no more than 3 words of the same condition are presented consecutively. Between the blocks, participants are presented with a break and are free to continue when ready. The entire experiment lasts about 60 minutes.

The stimuli for the morpheme interference experiment will be displayed using a platform for psychophysics and eye-tracking experiments (PSY) that was developed by Dr. Yoram Bonneh. The experiment is conducted in a quiet, dim lighted room. To get a reliable reading of the eye movements, the participants are seated with their chin located on a chin rest and their forehead resting against a similar metal frame. Participants are seated approximately 60 cm in front of a 22-inch monitor. On-ear headphones are used to present the auditory stimuli. The infrared camera that records the eye movements is located under the computer screen. Participants will be guided to look at the fixation point in the middle of the screen and to decide if the words they hear is a real word. Participants are told to click a button only if they hear a real word. At all times, a fixation point in the shape of a black circle is displayed in the middle of the screen. 1000 ms before the auditory stimuli, a green plus pops up at the center of the circle. Participants are given 2000 ms after stimuli onset to choose if to respond or not. Participants start with a block of 8 trials of practice that are not entered into the analysis.

5.2.1.1. MS data acquisition

Microsaccades will be measured in collaboration with Dr. Yoram Bonneh of the Vision Sciences Department at Bar Ilan. Oren Kadosh, a Ph.D. student in the lab, was a key person in developing the experimental procedure. Both Dr. Bonneh and Mr. Kadosh have agreed to work with us on this study and will be included in any publications resulting from this research.

Eye movements are measured using the Eyelink 1000 infrared system (2005-2009, SR Research Ltd.) with a sampling rate of 500 Hz. Both eyes will be recorded, although only measurements from the right eye will be used for analysis. A standard calibration of both eyes will be done before every session. The minimum microsaccade duration will be set to 9 ms. In order to differentiate the different eye movements from each other, the velocity will be set to 8 - 150º/s and the amplitude to 0.08 - 2º (eye movements that do not fit these standards will not be entered into the analysis). Blink measures in response to the two pseudowords conditions will be sampled as well (also bkRT). Blinks were defined as the same as in a previous study by Yablonski et al. (2017). First, blinks are defined as a period of time when the pupils are entirely obstructed. Second, eye movement will be analyzed in a vertical axis in a time of 100 ms before and 150 ms after each blink to verify the exitance of a blink. Third, the time period of a blink will be set to be between 250 and 700 ms in order to enter into the analysis. Similar to the rate of microsaccades, the recorded blinks will be divided into epochs, each represents a trial. Pupil diameter was suggested to indicate a cognitive load as well as msRT (Krejtz et al., 2018), for both visual and aural presented stimuli (Klingner et al., 2011; Liao et al., 2016). However, the pupillary dilation response (from the time the pupil diameter change until the return to baseline size) is longer than the microsaccadic response (seconds versus comparison to miliseconds, respectfully). This will require trials to be longer in order to allow the pupil size to return to baseline diameter. Due to the time constrains and the attempt to replicate Yablonski and Ben-Shachar (2017)’s previous study, we decided to use msRT as a measure of sensitivity to MIE.

Data preparation: msRT and bkRT will be recorded for all three conditions. The different rates are gathered from both eyes, but only the right eye will be entered into the analysis. Regarding msRT, every eye movement that is lower than 8º/s and above 150 º/s, and amplitude not between 0.08 - 2º will be rejected. Furthermore, microsaccades that are in the range of a blink recording will be rejected as well. Moreover, trials that don’t stand up to the quality of the recording (significance lower than 1) will be discarded.

To answer RQ2, different times of the trials will be entered into the analysis. As part of the research question and the research objective, the time of the MS inhibition will be examined to attempt and infer the time of the morphological process. As was mentioned previously, the time of the UP of each word will be examined and will be analyzed for each word due to the different UPs for each one (mean UP and range from word onset: Root 514.5 ms, 266 ms – 896 ms; No-root 560.5 ms, 346 ms – 869 ms). The differences in UP may cause a larger variance in epochs that are being analyzed. Entering every word's different UP will set each one in the time span of the trial in the significant point, and thus allow us to calculate the significance of the change in the occurrence of microsaccades. In addition to the UP analysis, an analysis of the end of each word will be performed as well. In the preliminary data that will be displayed later on, the msRT is being calculated only with the time of the beginning of the word. The focus on different points of analysis will lead us towards the time span of the morphological process of a spoken word.

5.2.2. Executive function task

After the word detection task, participants will perform an interference suppression assessment with the Bivalent Shape Task (BST) designed by Mueller and Esposito ((Mueller & Esposito, 2014). The task contains 5 blocks that have 20 trials each and take about a minute to complete. After every trial, feedback is given if the shape that was chosen is the correct answer or not. The task is built out of five types of block: practice (one trial of every condition), neutral (all trials contain a colorless stimulus), congruent (all trials contain stimuli that match in color to the corresponding shape at the bottom of the screen), incongruent (all trials contain a stimulus that doesn't match in color to the corresponding shape at the bottom of the screen), and a mixed block (contains 5 trials of every condition for a total of 30 trials).

The software will be run as a part of the Psychology Experiment Building Language (PEBL) Test Battery (Mueller and Piper, 2014) on a 13-inch monitor. At all times a red circle is displayed on the lower left side and a blue square is presented on the lower right side. On every trial, a shape appears in the center of the screen. Participants will be required to decide if the shape at the center of the screen is a circle or a square and click on the corresponding shape with a mouse. The color of the shape may vary (red, blue, or empty) but participants are directed to pay attention to the shape of the stimulus alone. Feedback of each trial is being presented after selection. Appendix D displays an example of every condition.

Data preparation: The error rate will be recorded and participants with error rates above 5% will be excluded from the analysis. The reaction time will be entered into the statistical analysis after excluding the erroneous responses. The data analysis will focus on the individual differences in the mean response time to the congruent and the incongruent trials in the mixed blocks to get the interference suppression cost as the difference between the two conditions. After assessing the IPC of every subject, it will be entered into a correlation analysis with the morphemic cost as seen in the msRT).

5.3. Statistical analysis

The steps of the statistical analysis will be done similarly to what was done in Yablonski et al. (2017). Data analysis will be done using an in-house software written in Matlab 2018b (The Mathworks, Natick, MA) by Dr. Yoram Bonneh, our collaborator on this project. The conditions that will be entered into the statistical analysis are the two pseudoword conditions (real-root vs. invented root). The real word condition will not be compared statistically to the pseudowords because they involve different responses. Furthermore, subjects are instructed to react with a button press only when presented with real words, so this condition is prone to motor confound.

Before statistical analysis, the LOWESS (locally weighted scatterplot smoothing) method will be used to optimize microsaccade extraction. To analyze the temporal delay of microsaccades, the data will be calculated per epoch (which represents an experimental trial) and is defined as the appearance of the first microsaccade after the stimulus onset. Because the onset of the auditory stimulus occurs 1 second after trial onset (see Appendix B), the period that will be looked at is from 1000 ms to 1500 ms to cover inhibition release even after the longest word (1160 ms). Thus, only significant differences in microsaccade rate during that period were checked. To assess the significance of the differences between real-root pseudowords and invented-root pseudowords, a nonparametric permutation test will be used. The calculated p-value will be derived from the fraction of permutations in which the original effect size exceeds the effect size in the randomly generated data.

After calculating the mean reaction time of the microsaccades in each condition (mean msRT), a morphemic cost will be assessed for each subject as follows:

$$[morphemic\ \ cost,\ \ subject\ \ X]_{RT} = \frac{meanMsRT(real\ root\ pseudowords)\ - meanMsRT\ (invented\ root\ pseudowords)}{\mathrm{meanMsRate\ (all)}}$$

To look into the type of relations between executive functions and microsaccade inhibition, an interference cost will be calculated for each of the participants by subtracting the mean RT in the congruent condition and dividing this difference by the mean score across all trials:

$$[Interference\ Cost,\ Subject\ X]_{RT} = \frac{meanRT\ (incongruent) - meanRT\ (congruent)}{\mathrm{meanRT(all)}}$$

Only the responses in the mixed blocks will be entered into the analysis. The trials of the mixed block have a higher interference effect due to the switch between conditions and require a higher level of cognitive demands (Czapka et al., 2020). We predict that the non-mixed blocks are not sufficient to emphasize the individual differences expected to emerge in the task. Furthermore, constructing the interference cost out of the RT from both types of blocks might involve the switching costs as well and not reveal the interference cost solely.

After calculating the interference cost for each of the participants, we will calculate a Pearson's correlation coefficient to assess the association between the interference cost and the MIE, as was calculated across subjects. If the costs are normally distributed, we will use Spearman's correlation coefficient instead.

6. Preliminary Results

Preliminary results are presented from three subjects. Two blocks from one of the participants were excluded because of insufficient quality of the eye-movement recordings. The focused time table in this data set is from 1000 ms, the time when the stimulus is presented, after the appearance of the fixation point. The significant delay is because it may cause an increase in the microsaccade rate (as seen in Figure 1 between 200 to 300 ms). Figure 1 displays a microsaccade inhibition to both of the pseudoword conditions. The response to real-root pseudowords displays greater inhibition than the response to the invented-root condition. The peak of the microsaccade inhibition is at 200 to 300 ms after the subjects heard a word. After inhibition, there is an enhanced microsaccade rate, which has a peak between 1300 and 1400 ms.

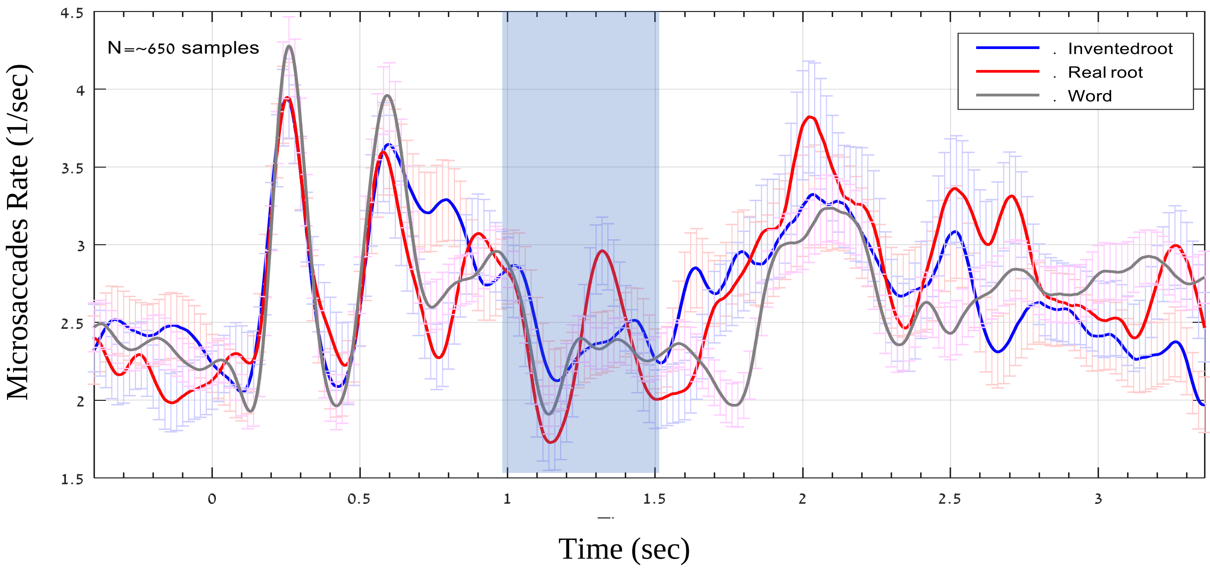
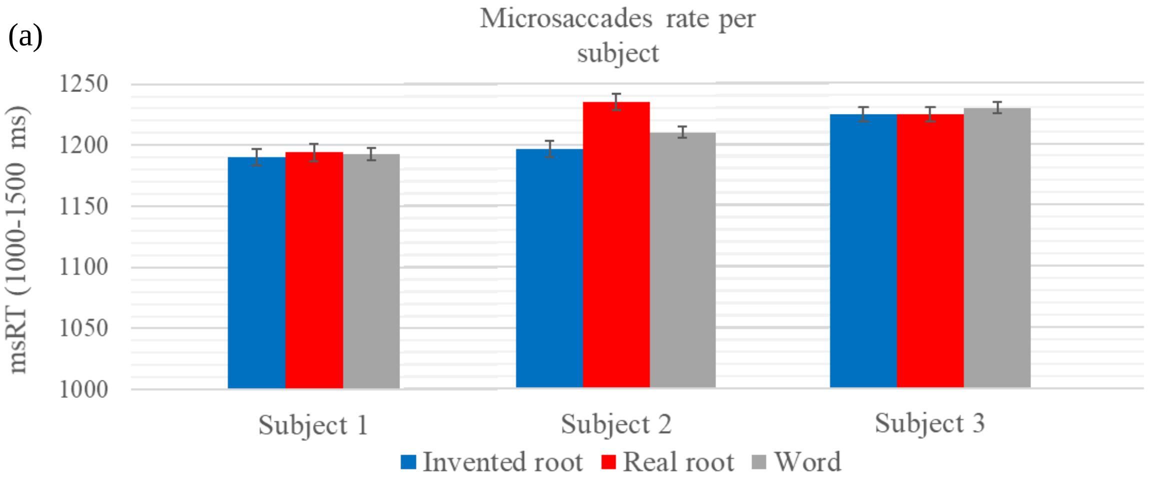


Figure 1. the modulation of microsaccadic rate. The figure displays the average rate of microsaccades for each condition, averaged across trials and subjects. Error bars represent standard error of the mean. The shaded rectangle represents the peak of rate inhibition and the enhanced rate afterward.

For the three participants, the preliminary results show a delay of a mean of 17 ms in the occurrence of real-root pseudowords as compared to invented-root pseudowords. The differences that are shown here are analyzed from the same time period, as was shown in Figure 2.



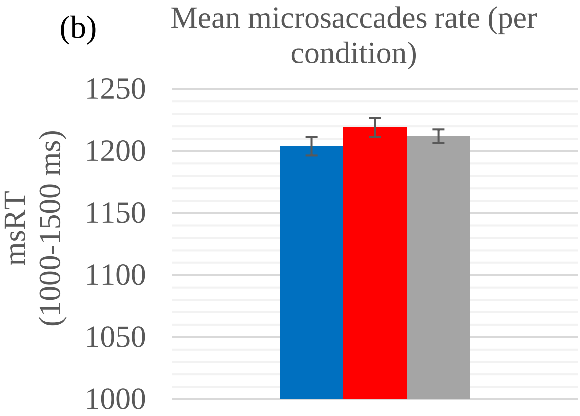


Figure 2 (a)-(b). The effect of word structure on the microsaccade inhibition. 3(a) presents the mean rate of microsaccades as it was averaged across trials and then across subjects (every 3 adjacent bars represent the msRT of one participant) and 3(b) presents the mean microsaccade rate for the three participants. The time course that was selected is 1000-1500 after the stimuli onset. Error bars represent standard error of the mean

Figure 3 displays the RT of the three subjects to the inhibitory control task. Two of the subjects showed a latency in response when the stimulus was incongruent in color to the correct matched shape (S1: 118.7 ms, S2: 104.4 ms). Error rates are not presented because all three subjects reached ceiling scores in the task (as expected for adult participants). It is worth mentioning that after the pilot results, a concern aroused that the different forms of presentation of the MIE stimuli (auditory) and the BST task (visual) will cause a problem to generalize the results to all modalities. Due to that, in further experiments, an auditory interference suppression assessment will be conducted as well.

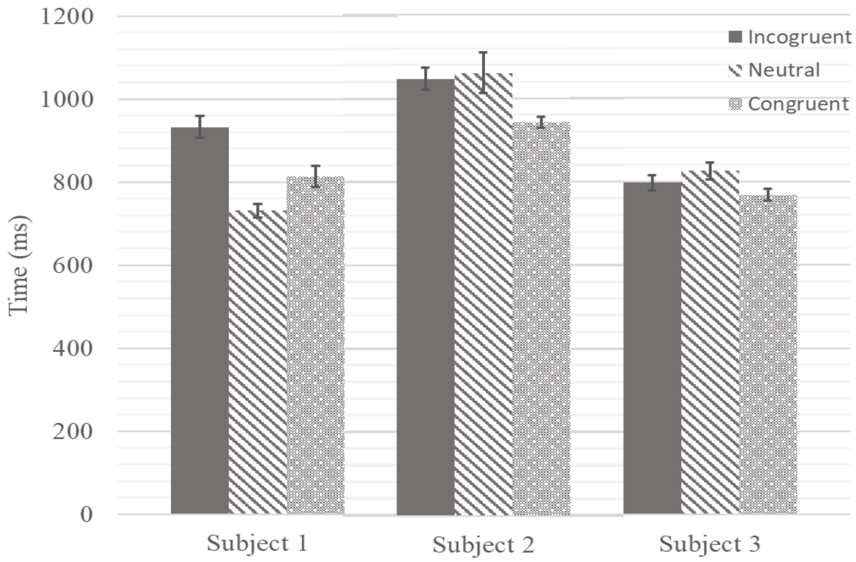


Figure 3. The mean reaction time of the three subjects that participated in the BST task. The neutral condition acts as the baseline (shapes with only black outlines). The mean scores represent the mean RT only in the mixed block (when all conditions were displayed together in random order). Error bars represent standard error of the mean over the trials in each condition.

These data only act as a preliminary set of results, and nothing significant is yet to be concluded. The first 3 participants in the data set showed a lower rate of microsaccades in the real root condition compared to the invented root condition (subject 2 had the most considerable difference). Furthermore, after inhibition, participants showed a bounce-back effect and a shoot in the microsaccadic rate. A larger set of data will allow as to see the effect of morpheme interference of spoken words via the measurement of the microsaccadic rate and will let us examine individual differences that are modulated by differences in executive functions.

In conclusion, our preliminary results indicate that investigating the effect of morpheme structure on microsaccades in the auditory modality is a direction worth taking. The ability to generalize the msMIE to other modalities serves as another piece of the puzzle to complete the model of morphological processing. This research can support the decomposition account and expand the cognitive domain of stimuli to which microsaccades are sensitive.

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Appendix A

Table 1.

Examples for stimuli in each condition

Condition	Examples (English transcript)	Hebrew Stimuli	Root
Real root pseudoword	ma**ʔane**ʃa[1]	מענשה	ע.נ.ש
	ksi**m**a	קסימה	ק.ס.מ
	ʃa**k**i**f**	שקיף	ש.ק.פ
Invented root pseudoword	ma**sd**e**l**a	מסדלה	*ס.ד.ל
	χi**g**u**l**	חיגול	*ח.ג.ל
	tvi**ʁ**a	טבירה	*ט.ב.ר
Real word	hit**l**a**h**a**v**ut	התלהבות	ל.ה.ב
	ʃvu**ʔ**a	שבועה	ש.ב.ע
	akaviʃ	עכביש	*no root*[2]

[1] The bolded letters in the second column represent the root, while the other letters are a part of the pattern.

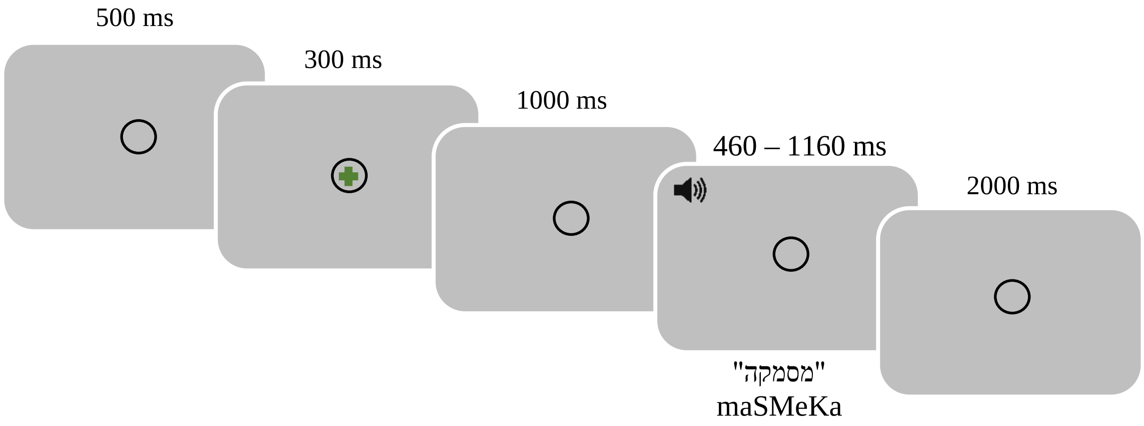
Table 2.

The number of words constructed from every pattern (in the pseudowords condition)[1]

	CaCiC	CCiCa	CiCuC	haCCaCa	hitCaCCut	maCCeCa
Real root pseudoword	7	6	9	11	9	8
Invented root pseudoword	9	8	9	10	7	7

[1] every word was presented twice.

Appendix B



A structure of a trial. This trial represents a trial when a subject's response is not needed (a real root pseudoword). The fourth step is when the pseudoword is being heard, which explains the time range of this step.

Appendix C

The stimuli that will be presented auditorily.

C.1. Real root pseudowords

Hebrew	Pronunciation	Hebrew	Pronunciation	Hebrew	Pronunciation
בילוט	bilut	התאסרות	hitʔasrut	מסמקה	masmeka
בליש	bališ	התבדקות	hitbadkut	מעלצה	maʔaleca
דיפוס	dipus	התבראות	hitbarʔut	מענשה	maʔaneša
דירוך	dirux	התגזרות	hitgazrut	מפרחה	mafrexa
דריג	darig	התחבשות	hitxabšut ʔa	מפתעה	mafteʔa
הגבשה	hagbaša	התחצבות	hitxacvut	מפתרה	maftera
הגלחה	haglaxa	התנשכות	hitnašxut	מקשבה	makševa
הגרדה	hagrada	התעמדות	hitʔamdut	משלפה	mašlefa
הגרשה	hagraša	התפגעות	hitpagʔut	נהיג	nahig
הזדרעות	hizdarʔut	התפרה	hatpara	נהילה	nehila
החבקה	haxbaka	התקצבות	hitkacvut	ניטול	nitul
החלצה	haxlaca	התרדפות	hitradfut	סביכה	svixa
הירוס	hirus	התרקדות	hitrakdut	סיגור	sigur
הכבסה	haxbasa	זיחול	zixul	עיקוץ	ikuc
הכשפה	haxšafa	זיכור	zikur	פזירה	pzira
הלחשה	halxaša	חביר	xavir	פחידה	pxida
הלטפה	haltafa	חזיק	xazik	פירוץ	piruc
הלכדה	halkada	חילום	xilum	צהילה	cehila
הלמדה	halmada	חשידה	xašida	צירוח	ciruax
המסרה	hamsara	טגינה	tgina	צמיח	camiax
הנגעה	hangaʔa	טפיס	tapis	צעיק	caʔik
הסחטה	hasxata	כביד	kavid	קסימה	ksima
הסתבלות	histablut	כיעוס	kiʔus	רדימה	redima
הסתלחות	histalxut	ליחוץ	lixuc	רטיב	rativ
הצלמה	haclama	לעיג	laʔig	ריחוב	rixuv
הקלחה	haklaxa	מבחשה	mavxeša	ריצוח	ricuax
השאבה	hašʔava	מגשמה	magšema	ריקום	rikum
השדלה	hašdala	מזרמה	mazrema	רמיז	ramiz
השטפה	haštafa	מחרזה	maxreza	רעישה	reʔiša
השמרה	hašmara	מחרקה	maxreka	שאיל	šaʔil
השתקלות	hištaklut	מחתרה	maxtera	שיתול	šitul
השתרפות	histarfut	מלבשה	malbeša	שליב	šaliv
התאגרות	hitʔagrut	מסלדה	masleda	שמינה	šmina
שקיף	šakif				

C.2. Invented root pseudowords

Hebrew	Pronunciation	Hebrew	Pronunciation	Hebrew	Pronunciation
אדיל	adil	השתמקות	hištamkut	מסדלה	masdela
אהיג	ahig	השתנמות	hištanmut	מעלשה	maʔaleša
בידון	bidum	התבלדות	hitbaldut	מקיב	makiv
בידוש	biduš	התגלנות	hitgalnut	מקמסה	makmesa
בירון	birun	התחנרות	hitxanrut	מקרדה	makreda
בליק	balik	התלרדות	hitlardut	מרשבה	marševa
בניק	banik	התמגחות	hitmagxut	מרשגה	maršega
בריץ	baric	התמכלות	hitmaklut	מרשחה	maršexa
גדין	gadin	התפלמות	hitpalmut	משדקה	mašdeka
גיבום	gibum	התפרלות	hitparlut	משלצה	mašleca
גריחה	grixa	התקצלות	hitkaclut	נבידה	nevida
דיפוש	dipuš	התקרפות	hitkarfut	נחידה	nexida
דירום	dirun	התרגדות	hitragdut	נקילה	nekila
דריל	daril	התרדבות	hitradvut	סביד	savid
האבמה	haʔavama	זיגור	zigur	סביקה	svika
הגרצה	hagraca	זקיל	zakil	סיבום	sibum
הדחגה	hadxaga	חזיפה	xazifa	סלין	salin
הדרקה	hadraka	חיגול	xigul	סמידה	smida
החגדה	haxgada	חליגה	xaliga	סרילה	srila
החרנה	haxrana	חליר	xalir	פימון	pimun
הטלמה	hatlama	חסיקה	xasika	צחיד	caxid
הלברה	halbara	חריל	xaril	צירוק	ciruk
הלמשה	halmaša	טבירה	tvira	קשינה	kšina
הלמתה	halmata	טריבה	triva	ריחוד	rixud
הלרשה	halraša	ליבוץ	libuc	ריצוב	ricuv
הלתחה	haltaxa	מברלה	mavrela	שדיב	šadiv
המחדה	hamxada	מדפגה	madpega	שחיגה	šxiga
המלשה	hamlaša	מדשרה	madšera	שיבוד	šibud
הנדקה	handaka	מחצדה	maxceda	שילור	šilur
הנמצה	hanmaca	מיסון	misun	שימול	šimul
הרדנה	hardana	מלטקה	malteka	שלין	šalin
השבמה	hašbama	מלקנה	malkena	שליסה	šlisa
השטבה	haštava	מניל	manil	שניח	šaniax
שנילה	šnila				

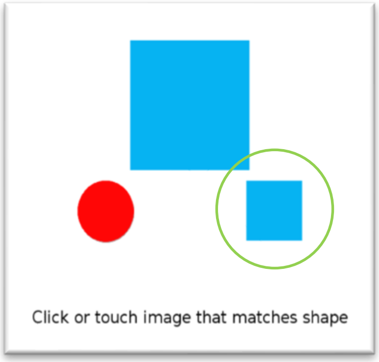
C.3. Real words

Hebrew	Pronunciation	Hebrew	Pronunciation	Hebrew	Pronunciation
אורווה	urva	טלסקופ	teleskop	פקודה	pkuda
אחוזה	axuza	טלפון	telefon	פרדוקס	paradoks
אידיאל	ideʔal	טניס	tenis	פתיל	ptil
אלבום	albom	טראומה	albom	צלילה	clila
אלכסון	alaxson	כניסה	knisa	צמיד	camid
אמונה	emuna	מכחול	mikxol	צנצנת	cincenet
אנטנה	antena	ממשלה	memšala	צעיף	caʔif
ארמון	armon	מנהרה	minhara	קולנוע	kolnoa
בלורית	blorit	מנעול	manʔul	קומקום	kumkum
בקבוק	bakbuk	מסעדה	misʔada	קינוח	kinuax
בקתה	bikta	מעצור	maʔacor	קינמון	kinamon
גיטרה	gitara	מערוך	maʔarox	קליפה	klipa
גלישה	gliša	נורמה	norma	קציר	kacir
גלריה	galerya	נזיר	nazir	קרנף	karnaf
דחליל	daxlil	ניתוק	nituk	קרסול	karsol
דייסה	daysa	נסיגה	nesiga	רובוט	robot
דרישה	driša	נשימה	nešima	רכיבה	rexiva
הדגשה	hadgaša	סיבוב	sivuv	רעידה	reʔida
הדיפה	hadifa	ספסל	safsal	שאיפה	šeʔifa
החלטה	haxlata	סרדין	sardin	שבועה	švuʔa
הכנסה	haxnasa	עטלף	atalef	שביתה	švita
העדפה	haʔadafa	עיגול	akaviš	שזיף	šezif
הצבעה	hacbaʔa	עכביש	akaviš	שטיח	šatiax
הצדעה	hacdaʔa	עכבר	axbar	שיזוף	šizuf
השכמה	haškama	עניבה	aniva	שינון	šinun
התלהבות	hitlahavut	עצירה	acira	שיפוע	šipua
התעמלות	hitʔamlut	ערימה	arema	שמיכה	smixa
התפטרות	hitpatrut	עתירה	atira	שקיעה	škiʔa
התרשמות	hitrašmut	פגישה	pgiša	שרביט	šarvit
ויסות	visut	פיהוק	pihuk	שריקה	šrika
זריקה	zrika	פיתול	pitul	תמיכה	tmixa
חלוקה	xaluka	פניקה	panika	תעריף	taʔarif
חליפה	xalifa	פסיעה	psiʔa	תריס	tris
תרנגול	tarnegol				

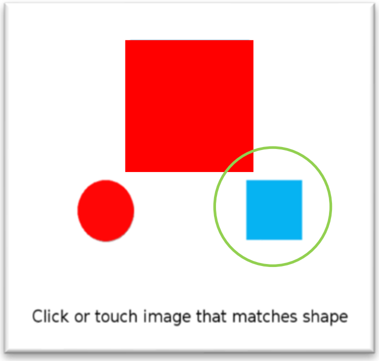
Appendix D

The three conditions of the Bivalent Shape Task as is presented to the subjects:

Congruent condition – the target stimulus match the corresponding shape in color, as well as shape.



Incongruent condition - the target stimulus doesn’t match the corresponding shape in color.



Neutral condition – the target stimulus doesn’t have a color, so the matching is in shape only.