絵画呼称課題における語彙意味選択に現れる調音の影響
Effect of overt speech on lexical-semantic processes during picture naming

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Abstract

Word production requires conceptual preparation, lexical processes, phonological processes, and motor preparation. Indefrey and Levelt (2004) proposed a serial progression model of speech production and the timings of individual stages. However, their model did not consider the effect of overt speech on early stages of word production. In order to clarify this effect, we recorded electroencephalogram from participants performing the following three tasks: naming, phonology, and category tasks. We found that task differences were observed sequentially in the time course as the model suggested. Moreover, a semantic interference effect was observed only in naming task. Our results suggest that the speech motor command of the word affects early lexical-semantic processes. We propose some modifications of the model to include cascade and interaction between stages.

Keywords — **speech production, lemma, semantic interference, EEG**

1. Introduction

We can state the name of what we see rapidly and easily. However, the cognitive processes underlying speech are not simple. In psycholinguistics, it is broadly agreed that there are four independent mental operations during word production: conceptual processing, lexical processing, phonological processing, and motor preparation (e.g., Strijkers and Costa [18]). Based on this assumption, Indefrey and Levelt [8] suggested the temporal dynamics of these operations in the brain involved in the production of a content word of a picture (i.e., picture naming task) using a meta-analysis of behavioral, electrophysiological, and brain mapping studies (I and L model, Figure 1). The I and L model presumes a modular theory of cognition, which means that independent brain regions are responsible for each cognitive stage. Moreover, the model assumes that those stages are processed in a serial fashion, supported by the temporal onsets of each component they suggested.

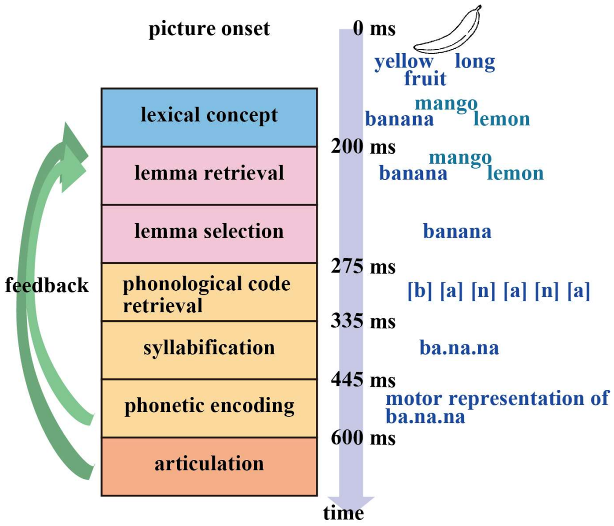

Figure 1. The cognitive stages of speech production and time course of the I and L model ([7], [8]) .

Although the I and L model suggests robust and elaborate temporal information regarding word production, Strijkers and Costa [18] pointed out that the I and L model was based on studies that did not use overt picture naming. The I and L model only focuses on what processing stages are needed for each task and what stages were affected in controlled conditions in previous studies. For example, in order to assume the onset time of phonological code retrieval, the model refers several studies with a phonological decision task, which requires participants to press a button, depending on the onset phonemes (consonants or vowels) of pictures names (e.g., Rodriguez-Fornells et al. [15]). Indefrey and Levelt [8] averaged those results and proposed that the onset time is 275 ms (Figure 1). However, how and which process stages different task goals affect the time course of speech production remain unclear.

Although the ERP is a powerful tool to investigate the time course of cognitive processes, only a limited number of studies have been tried recording electroencephalogram (EEG) with overt speech, because of the speech artifact. However, with the progress of technology, some recent studies have focused on the early stages of speech production that would not be affected by speech artifacts. Semantic interference during picture naming is one of the useful methods for investigating lexical processes before the stage of articulation that induces artifacts in EEG. During the continuous presentation of pictures of multiple semantic categories, stimuli in a later ordinal position within the same semantic category have a greater latency for naming (e.g., Howard et al. [6]; Costa et al. [3]) and lower accuracy rate (e.g., Navarette et al. [12]). This phenomenon is known to result from the cumulation of lemmas of the former target as competitors, as trials go by (Howard et al. [6]). Costa et al. [3] measured the ERP during picture naming with a cumulative semantic interference paradigm to investigate temporal information and they found that the ERP reflected semantic interference between 208 to 388 ms. This time window corresponds to lemma retrieval and lexical selection in the I and L model. However, whether the existence of overt speech affects semantic interference has not been investigated.

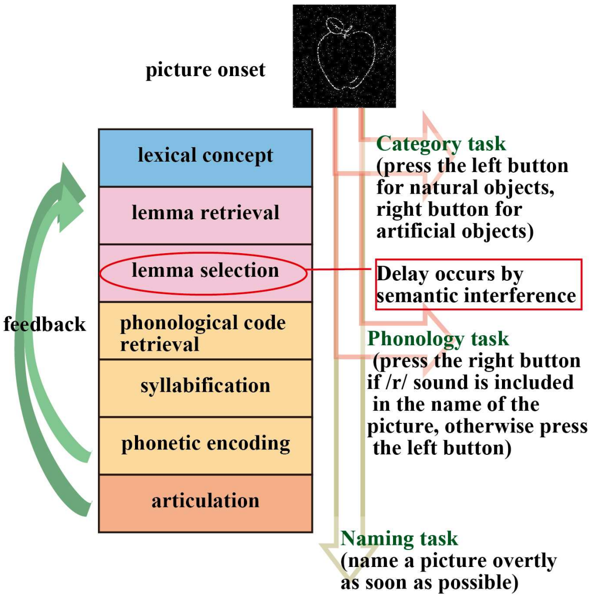

Figure 2. Tasks in the present study, and the different cognitive stages the tasks needed.

Internal and external self-monitorings do not occur in button-press decision tasks according to I and L model. While the I and L model assumes sequential progression, it is expected that the time course of stages that are earlier than phonetic encoding are not influenced by online feedback (green arrows in Figure 1). However, if a cascade is permitted, which means that later stages of speech production can be started before the former stages complete, there could be online feedback from later stages to earlier stages. Fink et al. [5] reported that the cumulative semantic interference effect appeared not only in the naming latency but also in the duration of the word spoken by participants. This result supports online interactions between articulation and the early stages of speech production.

In sum, the time course of speech production has been investigated with and without overt speech, it is still not clear that overt speech affects processing time. In the present study, we investigated whether overt speech affects the processing time of stages that are earlier than the stages expected to differ. To confirm the time course of the effect before the response is produced, we investigated the ongoing neural activation during overt speech using electroencephalography (EEG) during three speech production tasks: naming (picture naming task), phonology (phonological decision task), and category (categorical decision task) task (Figure 2). By comparing the ERP of these three tasks directly, we investigate whether the time window of the processes shows different processes. Thus, we can revisit the time course proposed in the I and L model. We also manipulated the sequence of the stimuli within the same category to induce a cumulative semantic interference effect on the lexical stage. If the motor command of overt speech produces an online feedback signal to early the stages before lemma selection totally ends, the semantic interference effect would be reflected qualitatively/quantitatively differently in the naming task relative to the other tasks. Otherwise, the naming task and phonology task, which progress over lemma selection, would show a semantic interference effect at almost the same time, with identical tendencies.

2. Methods

Participants Thirty Japanese native speakers participated (mean age = 21.1, SD = 3.55, 15 females), and the data from twenty-one participants with no history of brain-related disease whose data remained over 16 trials after artifact correction and error trial deletion were included in the following analyses (mean age = 21.6, SD = 3.13, 10 females). All participants had normal or corrected-normal-vision and did not suffer from oral-motor problems. Informed consent was obtained from all participants, and they were paid ¥1,000 per hour using a pre-paid card that could be used to purchase books. Ethical approval for the study was obtained from the Ethics Board of Minami-Osawa campus, Tokyo Metropolitan University.

Materials Seventy-two line-drawings were selected from Snodgrass & Vanderwart [17] and Nishimoto et al. [13]. The drawings consisted of four semantic categories: animals (18 items), plants (18 items), vehicles (13 items), and tools (21 items). We changed drawings to black backgrounds and white lines, and randomly picked white pixels and switched 40%, 60%, and 80% of them to background black pixels Pictures with 80% noise were used as fillers to raise attention (Figure 3). Pictures were resized to be 280 × 280 pixels. Because the vehicles category only included 13 items, we analyzed stimuli 2–13 within the same semantic category (Figure 4). The first item was not analyzed because prior studies have reported that the very first ordinal position shows longer word duration than the second (e.g., Fink et al. [5]). Filler stimuli were included in 13 orders. However, we did not include fillers and incorrect trials in the analysis.

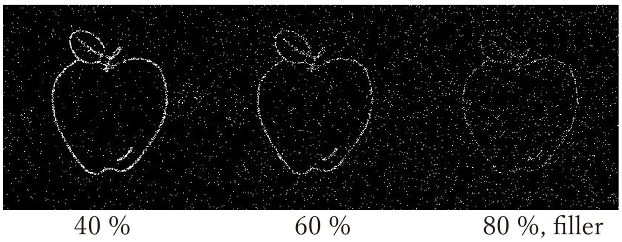

Figure 3. Pictures with three proportion of noises. Pictures with 80% noise were included when count ordinal positions, but not included in the analysis.

The standard names of the pictures in Japanese refer to Nishimoto et al. [13]. The property of the names are as follows: lexical frequency: M = 2,140, SD = 3,947.78 based on NINJAL-LWP for BCCCWJ (2011, National Institute for Japanese Language and Linguistics, Lago Institute of Language); familiarity: M = 5.16, SD = 0.94 according to Nishimoto et al. [13]; and number of mora: M = 3.32, SD = 1.2

Procedure Participants were tested individually in a shielded room. The monitor was 100 cm away from the participants, and the stimuli were presented on the monitor on a black background with a fixation cross that was 4 pixels long. The maximum visual angle for the stimuli was approximately 10 degrees. Three types of task were used: picture naming task (naming), phonology judgement task (phonology), and category decision task (category). In the naming task, participants were asked to overtly name the presented pictures as soon as possible. In the phonology task, they were asked to press the right button if /r/ sounds were included in the name of the picture, otherwise to press the left button on a response pad. In the category task, they were instructed to press the left button if the presented picture is a natural object and to press the right button for an artificial object.

Each task consisted of two separate sessions. One session consisted of 72 trials and every type of picture was presented once in a session. Stimuli were presented in a pseudo-randomized order; however, images from the same semantic category were not presented consecutively over three times. The second session of each task was in the same order as the first session with the pictures displayed left-right reversed. The order of tasks was counterbalanced. In each trial, a picture was displayed for 2,500 ms, followed by a black screen with a fixation cross with jitter set randomly to 1,250 ms, 1,500 ms, or 1,750 ms. The presentation of stimuli and response were controlled by STIM2 (Compumedics Neuroscan, Charlotte, NC, USA).

The pictures were not familiarized before the measurements; therefore, we performed a questionnaire survey of the names that participants used in the tasks after the completed EEG recording sessions. We decided the correct answers for each participant based on the answers of the questionnaire. However, if the answer of any picture was already used for another stimulus that was more appropriate (e.g., answer cabbage for pictures of lettuce and cabbage), or if it could be applied to multiple stimuli (e.g., answer flower for sunflower and there are other different types of flowers in the stimuli set such as rose), we regarded it as an incorrect response.

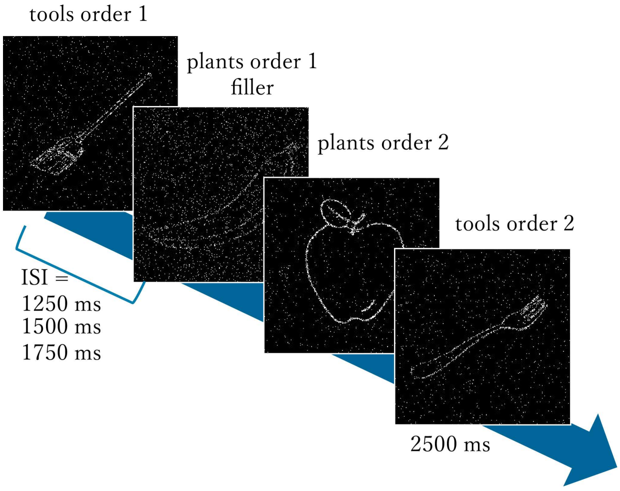

Figure 4. An example of stimuli and trial sequence.

EEG data acquisition The EEG was recorded with 64 electrodes in a cap (waveguard, ANT Neuro, Figure 5). We used BrainAmp DC (Brain Products) to amplify the data, with a sampling rate of 1,000 Hz. Electrode impedance was kept under 10 kΩ.

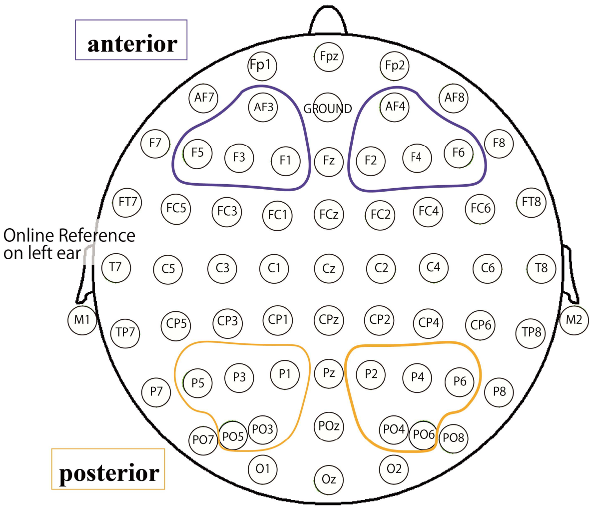

Figure 5. The placement of the electrodes.

Data analysis- behavior

Data from three ordinal positions (positions 2 to 4, 5 to 7, 8 to 10, and 11 to 13) were averaged, excluding incorrect answers and fillers. The reaction time for the phonology and category tasks, and accuracy for all tasks were analyzed. With the reaction time data, we performed a two-way analysis of variance (ANOVA) with tasks (two levels) and stimulus ordinal position within a semantic category (four levels). With the accuracy data, we performed two-way ANOVA with tasks (three levels) and stimulus ordinal position (four levels). A Greenhouse-Geisser correction was applied to all ANOVA results. Bonferroni's post hoc tests were performed for both the reaction time analysis and error rate analysis.

Data analysis- ERP

Using EEGLAB v.13.6.5 (Delorme & Makeig [4]) on MATLAB (R2016b, MathWorks, Massachusetts, USA), EEG data were bandpass filtered between 0.143 Hz and 30 Hz. Continuous data were segmented from 200 ms before stimulus onset to 3,500 ms after onset. The baseline correction was carried out based on the 200-ms pre-stimulus interval. If any single electrode showed a potential change over 70 µV in 1,000 ms from the beginning of an epoch, that datum was rejected as artifact contaminated. For each time point, the data recorded from each electrode were subtracted in reference to the averaged data of all electrodes except M1 and M2 after artifact rejection.

Electrodes were grouped into four areas: left anterior (AF3, F1, F3, F5), right anterior (AF4, F2, F4, F6), left posterior (P1, P3, P5, PO3, PO5), and right posterior (P2, P4, P6, PO4, PO6). We performed two-way ANOVAs with tasks (three levels) and stimuli ordinal position (four levels) for each time point averaged within a 31 ms time window for each area. The statistical threshold was set at the 0.05 alpha level. In order to investigate the task effect, Tukey-Kramer's post hoc tests were performed. To investigate the semantic interference effect for each task, we performed Spearman's correlation test between stimulus ordinal position (positions from 2 to 13) and potential changes in ERP in a 31-ms time window for each task and in each area.

3. Results

Behavior

The reaction time for the phonology task was 1,400.60 ms (SD = 178.81) and 916.62 ms (SD = 117.96) for the category task. The two-way ANOVA of reaction times with task and stimulus ordinal position showed a significant main effect of task ($F = 82.72$, $p < 0.0001$) and stimulus ordinal position ($F = 4.24$, $p = 0.021$). Post hoc testing revealed that the difference between the reaction time of the phonology task and that of the category task was significant ($t = 15.675$, $p < 0.001$). Post hoc testing for stimulus ordinal position was not significant.

The average accuracy for each task is shown in Figure 6. The two-way ANOVA of accuracy showed a significant main effect of task ($F = 230.44$, $p < 0.0001$) and stimulus ordinal position ($F = 12.83$, $p = 0.0001$). The post hoc test revealed that the accuracy of the last ordinal position was different from the accuracy of the other positions (11–13 vs. 2–4, $p < 0.001$; 11–13 vs. 5–7, $p = 0.02$; 11–13 vs. 9–11, $p = 0.003$). Post hoc analysis also revealed that the accuracy of the category task was highest, followed by the naming task, and that of the phonology task was the lowest (category-naming, $p < 0.001$; category-phonology, $p < 0.001$; naming-phonology, $p < 0.001$). The interaction between the two factors was significant ($F = 10.50$, $p < 0.0001$). Post hoc testing revealed that the accuracy of the last ordinal position (11–13) was significantly lower than that of the first ordinal position (2–4) in the naming task ($p < 0.0001$). In contrast, in the phonology task, the accuracy of the third position (8–10) was significantly higher than that of the other positions (8–10 vs. 2-4: $p = 0.006$; 8–10 vs. 5–7: $p = 0.007$; 8–10 vs. 11–13: $p = 0.002$), and that of the last position (11–13) was significantly lower than that of the first position (2–4) ($p = 0.003$).

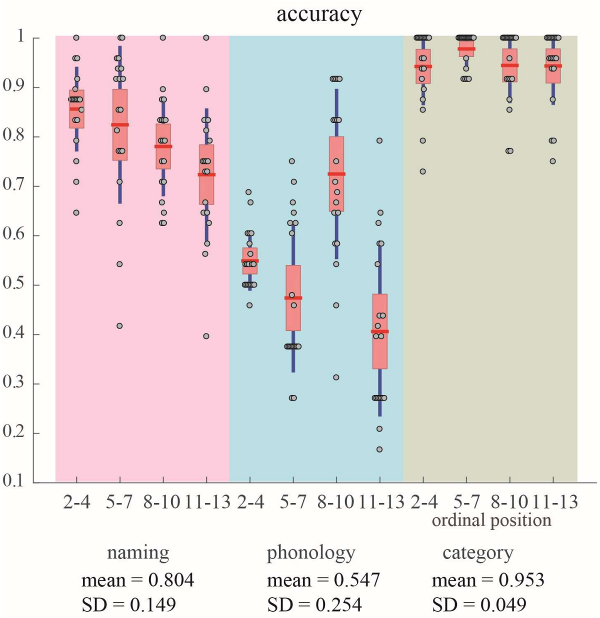

Figure 6. Accuracy in each task for each ordinal position. Each dot on the graph refers to the mean data from a participant.

ERP

We performed repeated measures two-way ANOVAs with stimulus ordinal position (4) × task (3) for each time point in each area. We omitted the results that were sustained for less than 30 ms from further analyses. With alpha level = 0.05, the main effects of task were found in all areas: left anterior (762–1,906 ms), right anterior (775–1,600 ms), left posterior (470–1,824 ms), and right posterior (501–665 ms). The main effects of stimulus ordinal position were found in all areas as well: left anterior (91–231 ms), right anterior (80–174 ms), left posterior (89–251 ms), and right posterior (116–215 ms), (Figure 7). Interaction between the two factors were found in the left posterior region from 435 ms and in the right posterior region from 802 ms.

In order to investigate task effect, multiple comparisons with Tukey-Kramer's test were performed. Significant differences were only found between the naming task and category task in all areas (left anterior: from 758 ms; right anterior: from 650 ms; left posterior: from 516 ms; right posterior: from 509 ms). However, because the wave form of the phonology task was different from the naming task after the time window of the category task and naming task diverges, we performed Tukey-Kramer's post hoc test only with the task factor. Figure 7 shows the ERP waveform of each task in each area and the results of the one-way post hoc test. In the left anterior region, the naming task was different from the category task from 749 ms and was different from phonology task from 811 ms. In the right anterior, the naming task was different from the category task from 645 ms and different from the phonology task from 829 ms. In the left posterior area, the ERP of the naming task diverged from the category task from 503 ms. Similarly, the ERP of the phonology task diverged from that of category after 530 ms. The naming and phonology tasks differed from 775 ms.

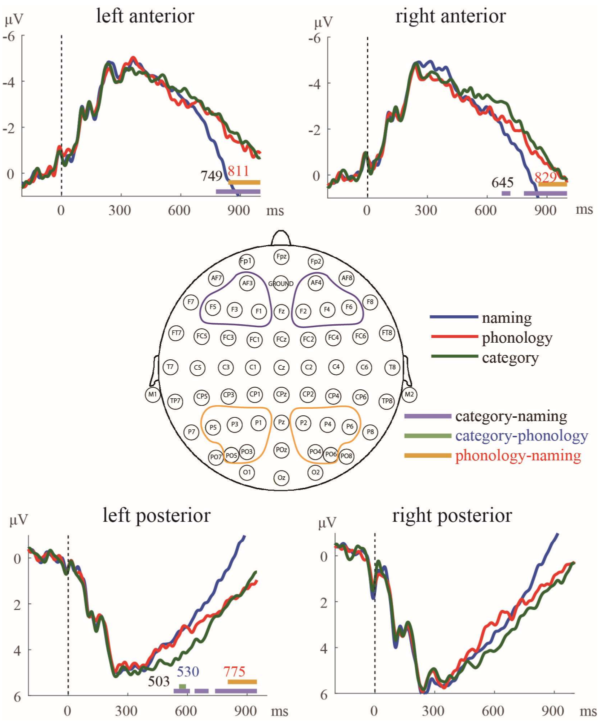

Figure 7. ERP waveforms of the three tasks. Bar graphs below indicate the significant differences in the post hoc test with 31-ms time-windows (blue: category task vs. naming task, orange: phonology task vs. category task, yellow: phonology task vs. naming task). The number above the bar graph is the onset time that starts to appear statistically significant that last more than 30 ms.

In order to confirm any task-driven effect in the lexical processes, we performed multiple comparison with a Tukey-Kramer's test of the average of the time window where the main effect of the ordinal position was found. In the left anterior area, ordinal positions 2–4 and 8–10 were significantly different at 652–725 ms (p = 0.036). In the left posterior area, three time windows showed significant differences between positions 8–10 and the other positions (89–250 ms: position 5–7 vs. position 8–10, p = 0.003; 297–364 ms: position 5–7 vs. position 8–10, p = 0.004; 369–544 ms: position 2–4 vs. position 8–10, p = 0.005, position 5–7 vs. position 8–10, p = 0.019). In the right posterior area, at 116–214 ms the difference between position 2–4 and position 8–10 was significant (p = 0.026).

In order to confirm interactions between the task and ordinal position, we confirmed the correlation between stimulus ordinal position (2–13) and potential change in each task and in each area using Spearman's correlation coefficient (Figure 8). Only in the naming task, the significant correlations between stimulus ordinal position and potential change were found in the left anterior area (117–206 ms: $r = -0.813$, $p < 0.005$), and in the right posterior area (112–328 ms: $r = 0.870$, $p < 0.005$).

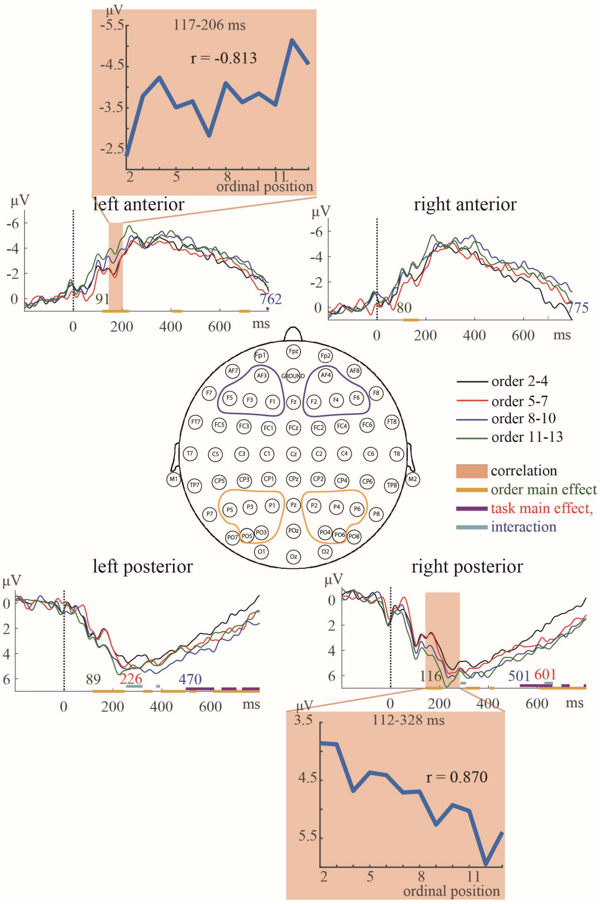

Figure 8. ERP waveforms of stimulus ordinal positions in the naming task. The data of the three stimuli sequences within the semantic category were averaged sequentially: 2–4, 5–7, 8–10, and 11–13. The graphs in the orange boxes show the average potential of the time window where the correlation of the position (2–13) and potential change were significant.

4. Discussion

In the current study, we examined whether overt speech affects lexical processes in word production during picture naming. We conducted different language production tasks that require different goals, with the sequence of the stimuli within the same category to induce a cumulative semantic interference effect on the lexical stage. We found the time interval of the two task differences (naming and phonology task vs. naming and category task) were reflected in the ERP in the time window that the I & L model proposed. However, the result indicates that the semantic interference effect was only found in the naming task that requires a speech motor command of the lexical word. This result cannot be explained with the I and L model, which does not assume the influence cascade model.

The present accuracy results imply that the accuracy of each task was different from that of the others. The accuracy in the phonology task was the lowest, followed by naming task, with the highest accuracy in the category task. Moreover, the latest ordinal position (11–13) shows significant differences from the other ordinal positions in the naming and phonology tasks. However, the relationship between accuracy and stimulus ordinal position in the naming task and phonology task were different. In the naming task, the latest stimuli ordinal position (11–13) had lower accuracy than the early stimuli ordinal position (2–4), whereas the accuracy in the phonology task was highest at ordinal position 8–10. The results in the naming task reflect the typical semantic interference effect, which can be seen as longer reaction times and/or lower accuracies at later stimulus ordinal positions.

Task differences in the ERP data were observed in a later time window than that suggested by the I and L model. It is assumed that in the category task, it is not necessary to access or select the lemma; therefore, differences between the category and naming tasks were expected to be seen from 200 ms after picture onset. In addition, since the phonology task does not require the phonetic code of a word, we hypothesized that the phonology task and naming task would show differences from 445 ms, as that is the time course that the I and L model suggests for the start of phonetic encoding. However, both time courses of the task difference in the current study were statistically significant 300 ms later than expected in the left posterior area. The time interval of the two task difference effects (phonology task [775 ms] – category task [503 ms] = 272 ms) was consistent with the I and L model (onset of phonetic encoding [445 ms] – onset of lemma retrieval [200 ms] = 225 ms). This result implies that the cognitive stages of speech production essentially progress in serial sequence. Moreover, the time course of speech production without overt speech are consistent with the suggestions of the I and L model.

As mentioned above, the semantic interference effect was observed in task performance accuracy. We used thirteen items for four semantic categories in the present study. This is not a traditional method to evoke cumulative semantic interference, which uses more categories and fewer item numbers. However, we successfully elicited the semantic interference effect in accuracy and the ERP. The last ordinal positions (11–13) had lower accuracies than the earlier ordinal positions (2–4) in the naming and phonology task. However, the ordinal position 8–10 of the phonology task was higher than the other two earlier ordinal positions (2–4 and 5–7) in the phonology task. This tendency is not a typical semantic interference effect. In correspondence with these results, the correlation between stimulus ordinal position (2–13) and ERP was only significant in the naming task. The semantic interference effect caused by the stimulus ordinal position within a category is often mentioned to be a result of increasing competition between candidate lemmas in lemma selection (e.g., Costa et al. [3]; Howard et al. [6]). However, according to the I and L model, the phonology task needs to generate lemma to encode phonological code for the semantic interference effect to appear.

Several possibilities are conceivable to explain our results. First, the feedback from phonetic encoding could affect lemma selection stage before it is completed. If the cascade manner of progression could be adopted, the feedback signals make the activation of lemma and competitor higher. Because the I and L model assumes that the first feedback occurs internally after the phonetic code is generated (Figure 1), it is no wonder that only the naming task shows semantic interference effect that was affected by the feedback signal in the current study. This account is also in line with the finding that there are interactions between lexical access and articulation, even after articulation starts (Fink et al. [5]).

Second, task difficulty could weaken a semantic interference effect. Abdel Rahman and Sommer [1] explored whether the difficulty of semantic classification would affect the onset time of phoneme decision by using EEG. They utilized a complex design with go/no-go responses and a semantic classification task. They reported that with difficult semantic classification task (herbivore vs. omnivore), phonological no-go lateralized readiness potential (LRP) was not observed. Further, the difficulty of semantic go/no-go decision task did not affect the onset of phonological processes. Because the serial model predicts the latter stages (phonological processes) linearly delayed, they proposed partially parallel progress of semantic and word form retrieval. However, in the present study, a difficulty to answer the phonology task would arise after phonological features of a picture name are retrieved. Therefore, it is unlikely that lexical stages are affected by the task difficulty and the delay of lemma selection is canceled. Further research with tasks using similar difficulties will probably be needed.

On the other hand, this account is incompatible with the result that Abdel Rahman et al. [2] reported. They investigated the task difference in semantic interference in the picture word interference (PWI) paradigm in comparison with the picture naming task and phonological decision task with button pressing. As a result, they reported a semantic interference effect in both tasks. However, the PWI paradigm is significantly different from the continuous presentation we used because the distractor is compulsorily activated in PWI. In PWI, the semantically related/unrelated written word is simultaneously presented on the target picture, which means that phonetic information is already generated with or without articulation. It is not strange that even in a phonological decision task, information from the phonetic encoding of the distractor delays lexical stages, such as lemma selection.

The time window where correlations were observed was between 112 to 328 ms (117–206 ms in the left anterior area; 112–328 ms in the right posterior area). This time window was earlier than expected, corresponding to the time between lemma retrieval and lemma selection. However, we used the upper level of semantic category (basic level) rather than an often-used level (i.e., subordinate level), which means semantic interference could occur earlier. Moreover, Miozzo et al. [11] reported that effect from semantic features starts from 150 ms. This result suggests that semantic processing including lemma selection could be started earlier than the I and L model suggests. Even if the semantic interference effect we observed was from conceptual processing, it is consistent with the feedback account we suggested because it is assumed that feedback in speech is sent to the lexical conceptual stage according to the I and L model. Moreover, this argument enables discussion of the stages where interactions occur.

Despite it was not so conclusive, we observed the main effect of the ordinal position at late time windows (652–725 ms in left anterior area; 297–364 ms and 369–544 ms in left posterior area). Krott et al. [10] reported a semantic interference effect that was reflected in ERP at similar time windows (270–310 ms, 440–510 ms, 520–560 ms, and 630–670 ms). They discussed that the two earlier time windows reflect lemma retrieval and phonological code retrieval stages, followed by the two later time windows for the later stages or the self-monitoring. Furthermore, they reported increasing in high beta band power before 150 ms from responses and interpreted the increase reflects the exclusion of uncertain responses from semantic distractors. However, the polarity of ERP they observed was the opposite of our results. Also, they used written word distractor that is simultaneously presented above the picture, which could be directly converted to phonetic information (e.g. Navarette et al. [12]). Although the locus of semantic interference effect has not been completely clarified yet, the present results suggest that multiple factors running in the cascade manner cause the effect, which appears in the early and late time windows of ERPs.

5. Conclusion

In summary, the present study partly supports the sequential progress of speech production proposed in the I and L model. However, from the result of the semantic interference effect, which was observed only in naming task, we suggest that the speech motor command of the word could affect the early stage of speech production, such as lexical processes, through the feedback from phonetic code. For this reason, it is necessary to modify the I and L model to include cascade and interaction between stages and to further investigate the time course of each stage with tasks that demand different aspects of overt speech.

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